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Technical Progress Report for the Quarter
1 April — 30 June, 1981

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Office of Nuclear Waste Isolation

Battelle Memorial Institute
505 King Avenue
Columbus, OH 43201

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BATTELLE Project Management Division

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OVERVIEW

by

Neal E. Carter
General Manager

THE ONWI TECHNICAL PROGRAM

This report describes the technical accomplishments during the period from April through June, 1981, on the commercial nuclear waste management programs under the direction of the Office of Nuclear Waste Isolation (ONWI).

The National Waste Terminal Storage (NWTS) program was established in 1976 and given the responsibility of developing a system for the permanent isolation of nuclear wastes. NWTS is part of the Office of Nuclear Waste Management in the U.S. Department of Energy. The establishment of NWTS signaled the acceleration of the national program.

The purpose of the NWTS program is to develop the technology and facilities required for the disposal of commercial spent nuclear fuel, defense high-level waste, and transuranic waste, ensuring public health and safety and protection of the environment. The program includes facilities for receiving, encapsulation, and disposal of wastes.

The scope of the NWTS repository development effort includes comprehensive geologic exploration, technology development, equipment testing, and model verification activities, as well as the design, licensing, construction, operation, and decommissioning activities required to provide geologic repositories and spent fuel handling and packaging facilities. Development of the technology, methodology, and facilities for interim spent fuel storage, waste treatment, and waste transportation, which are interfacing activities with the terminal isolation activity in the national waste management program, are being carried out in other DOE efforts.

ONWI has lead responsibilities in the NWTS structure for oversight and for development of the general technology, and for geologic exploration of non-DOE land. A project management group, ONWI directs and evaluates studies, research, and development performed by subcontractors on repository sites and designs.

The scope of ONWI activities includes providing the technology and facilities for the terminal isolation of these wastes by disposal in mined repositories deep underground in stable geologic formations. Steps leading to the accomplishment of that purpose include:

- Site exploration, characterization, and recommendation
- Design, licensing, construction, and operation of a commercial geologic repository (or repositories)
- Technology development to support these steps.

Throughout the process, ONWI has the responsibility to provide public information on all aspects of the program and to encourage public interaction.

It is recognized that safety of the public is the overriding program objective. The technical programs have been formulated to meet the challenge of the NRC licensing process, which is the institutional mechanism for assuring the public protection has been accomplished.

The ONWI program is organized into eight tasks, each one being a level-two element in the NWTS program standard Work Breakdown Structure (WBS).

WBS Element	Task Title
1.1	Systems
1.2	Waste Package
1.3	Site
1.4	Repository
1.5	Regulatory and Institutional
1.6	Test Facilities and Excavations
1.7	Land Acquisition
1.8	Program Management

The purpose of the Systems Task is to transform the statement of the ONWI mission into a set of objectives and requirements (the baseline) for the ONWI program and to allocate these to each of the remaining tasks. The Systems Task defines the overall strategies and alternatives that will be considered in proceeding toward the goal. It defines subsystems and their interfaces and develops the criteria to be used to determine whether the requirements of the subsystems have been met. It also provides an integrated assessment of the predicted system performance to assure that the overall system requirements have been met.

Conceptually, the geologic repository is viewed as a waste isolation system made up of three functionally distinct but interacting subsystems which provide multiple natural and human-made barriers to the release of the contained waste into the biosphere. The subsystems correspond to the first three tasks: the waste package, the site, and the repository (Figure 1).

The Waste Package Subsystem (or Task) is an important part of the overall waste disposal system. During the repository operational phase, the waste package provides safe containment for the waste material during handling and emplacement operations and helps ensure that the waste can be safely retrieved from the repository, if necessary.

In the long term, the waste package provides containment during the thermal period (the time the fission products are decaying), and provides redundant, long-term waste isolation capabilities beyond the thermal period. The waste package will include the waste form itself and a system of engineered barriers that may consist of filler material, a canister, and one or more layers of protective materials selected to minimize interactions among the waste, the host rock, and any ground water that might enter the repository.

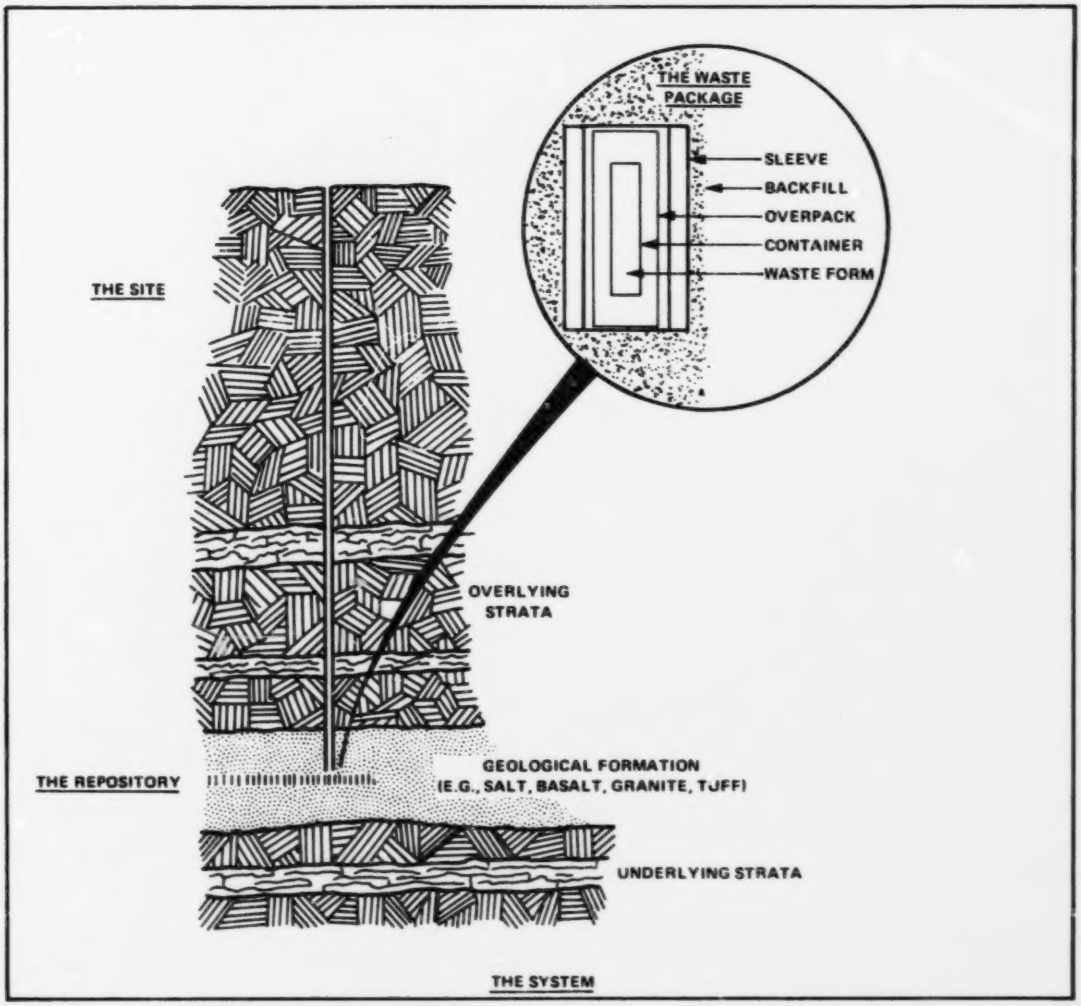

THE WASTE PACKAGE
SLEEVE
BACKFILL
OVERPACK
CONTAINER
WASTE FORM
THE SITE
OVERLYING STRATA
THE REPOSITORY
GEOLOGICAL FORMATION (E.G., SALT, BASALT, GRANITE, TUFF)
UNDERLYING STRATA
THE SYSTEM

Figure 1. Geologic Disposal System.

The Site Subsystem (or Task) includes natural barriers which provide waste containment and isolation. These barriers will keep radionuclides from reaching people in unacceptable quantities by (1) maintaining the waste in its emplaced position for a very long period of time (i.e., providing waste containment); (2) limiting radionuclide mobility through the geohydrologic environment to the biosphere (i.e., providing isolation); and (3) making inadvertent human intrusion difficult by locating the repository deep in a host rock. The site will contain a host rock suitable for construction of the repository and containment of the waste, as well as surrounding rock formations which can provide adequate isolation. The associated hydrologic system will exhibit low ground-water flow rates, long flow-path lengths to the biosphere, and evidence of long-term stability. The important natural attributes of the host rock will include its hydraulic and chemical characteristics, which determine ground-water flow rates and the dispersion rates of any dissolved waste products; and its thermal-mechanical characteristics, which determine the stability of the host rock to withstand the thermal effects produced by the decay of the fission products in HLW.

The Repository Subsystem (or Task) (Figure 2) will consist of the man-made structures that permit access to the underground facilities and enhance waste containment, and natural barriers, such as the local host rock, that provide containment and isolation after closure. The design, construction, and operation of the repository will be carried out in a manner that preserves the containment and isolation capabilities of the particular site. Surface facilities will provide for waste receipt, preparation of the waste for emplacement, and transfer of the waste to the underground workings. Repository facilities at depth will include a receiving area for transfer of waste packages to the emplacement holes and equipment to emplace auxiliary barriers, backfill, and other shielding.

The Regulatory and Institutional Task serves to obtain the regulatory, social, and political acceptance of the proposed repository system, without which the mission could not succeed. This task develops criteria that will assure protection of the public health and safety and the environment, and provides the documentation required by the NRC for its review and action before a license to contruct is issued to DOE. Not only is public review of the proposed repository project a part of the licensing process, but the DOE has an extensive program to provide all data developed by the program to the public. In addition, under the provisions of the National Environmental Policy Act, all major actions contemplated by DOE will be documented and subject to public review.

The Test Facilities and Excavations Task provides facilities, both in the laboratory and in the field, required to provide physical data and verification of models to be used in design and licensing applications. The acquisition of test facilities requires long lead times, and their need must be justified far in advance of actual operation. Their use will extend beyond the technology phase, being required during design and the subsequent licensing process, to evaluate or demonstrate operability, safety, and reliability. The in situ field facilities allow an

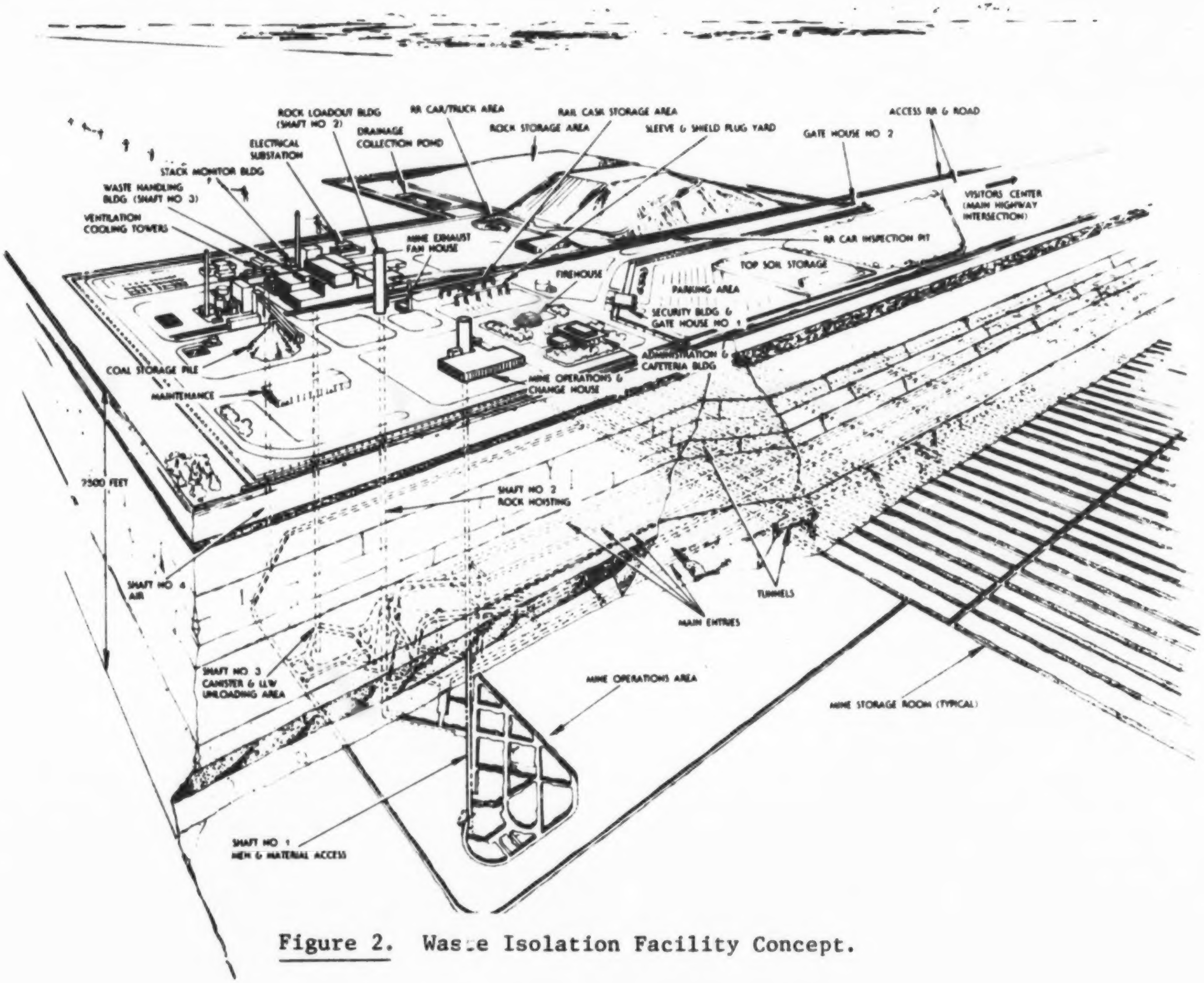

ROCK LOADOUT BLDG (SHAFT NO 2)
RR CAR/TRUCK AREA
RAIL CASK STORAGE AREA
ROCK STORAGE AREA
SLEEVE & SHIELD PLUG YARD
GATE HOUSE NO 2
ACCESS RR & ROAD
DRAINAGE COLLECTION POND
ELECTRICAL SUBSTATION
STACK MONITOR BLDG
WASTE HANDLING BLDG (SHAFT NO 3)
VENTILATION COOLING TOWERS
VISITORS CENTER (MAIN HIGHWAY INTERSECTION)
MINE EXHAUST FAN HOUSE
RR CAR INSPECTION PIT
TOP SOIL STORAGE
FIREHOUSE
PARKING AREA
SECURITY BLDG & GATE HOUSE NO 1
ADMINISTRATION & CAFETERIA BLDG
COAL STORAGE PILE
MINE OPERATIONS & CHANGE HOUSE
MAINTENANCE
2500 FEET
SHAFT NO 2 ROCK HOISTING
SHAFT NO 4 AIR
TUNNELS
MAIN ENTRIES
SHAFT NO 3 CANISTER & LLW UNLOADING AREA
MINE OPERATIONS AREA
MINE STORAGE ROOM (TYPICAL)
SHAFT NO 1 MEN & MATERIAL ACCESS

Figure 2. Waste Isolation Facility Concept.

experimental integration of the repository subsystems in actual demonstrations of the interactions between the waste package, the repository, and the site.

The Land Acquisition Task will enable preferred sites to remain inviolate after they have been chosen and will see the proper legal procedures are followed in the acquisition process.

The programs required are enumerated in the Work Breakdown Structure (WBS) shown in Figure 3. Progress on various elements of this Work Breakdown Structure is reported in this Quarterly Report in accordance with the WBS elements.

QUARTERLY HIGHLIGHTS

Major accomplishments during this quarter are listed below.

SYSTEMS

- A computer model was developed to assist in preparing preliminary estimates of repository costs and the cost impact of design changes. The model uses cost data from numerous detailed architectural and engineering estimates as a basis.

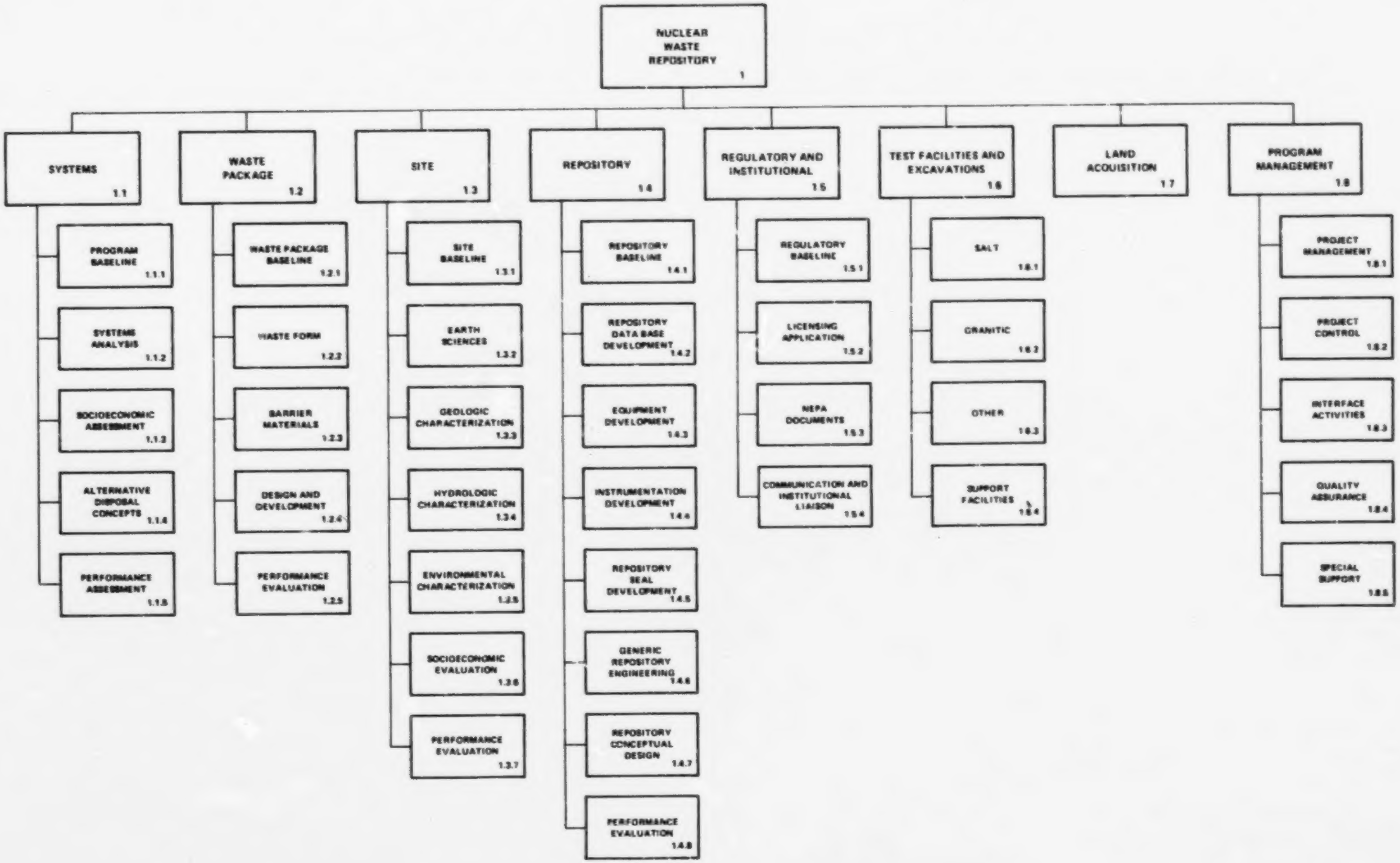
- Significant progress was made in the laboratory research on the closure of fractures under conditions of high temperature and pressure. New methods of measuring the extent of fracture closure are now being developed.

- The two-dimensional analytical transport code, UCBNE 25, which predicts radionuclide concentration in steady ground-water flows, was used to predict the far-field migration of radionuclides released from waste packages at WIPP and BWIP. An additional code for radionuclide transport through a fractured rock has been modified to include decay chains.

- A method was developed which yields physical insight into leach rate trends while minimizing the required mathematical effort. A necessary condition, at this time, is the time-invariance of the parameters used to represent the mechanisms controlling waste form leaching.

WASTE PACKAGE

- A study on spent fuel disassembly alternatives is under way to assess the impacts of five alternative spent fuel waste forms for geologic disposal and to recommend the reference form. After assessments were made on technical, operating, safety, and economic bases, the results, when used with the figure-of-merit methodology developed at the initiation of the studies, resulted in the option of disassembly and close packing as the reference disposal waste form.


NUCLEAR WASTE REPOSITORY 1
SYSTEMS 1.1
PROGRAM BASELINE 1.1.1
SYSTEMS ANALYSIS 1.1.2
SOCIOECONOMIC ASSESSMENT 1.1.3
ALTERNATIVE DISPOSAL CONCEPTS 1.1.4
PERFORMANCE ASSESSMENT 1.1.5
WASTE PACKAGE 1.2
WASTE PACKAGE BASELINE 1.2.1
WASTE FORM 1.2.2
BARRIER MATERIALS 1.2.3
DESIGN AND DEVELOPMENT 1.2.4
PERFORMANCE EVALUATION 1.2.5
SITE 1.3
SITE BASELINE 1.3.1
EARTH SCIENCES 1.3.2
GEOLOGIC CHARACTERIZATION 1.3.3
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EQUIPMENT DEVELOPMENT 1.4.3
INSTRUMENTATION DEVELOPMENT 1.4.4
REPOSITORY SEAL DEVELOPMENT 1.4.5
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SUPPORT FACILITIES 1.6.4
LAND ACQUISITION 1.7
PROGRAM MANAGEMENT 1.8
PROJECT MANAGEMENT 1.8.1
PROJECT CONTROL 1.8.2
INTERFACE ACTIVITIES 1.8.3
QUALITY ASSURANCE 1.8.4
SPECIAL SUPPORT 1.8.5

Figure 3. ONWI Work Breakdown Structure.

- Preparations continued for the shipment of the glass HLW log to NTS/EMAD. All of the cask-handling and shipping hardware has been fabricated and accepted. The cask-handling procedure is completed and approved.

- Phase stability studies in waste form and material studies continue to focus on the structural integrity of ceramic waste forms. Several ceramic samples of cesium hollandite and potassium hollandite were produced; their densities of 80 to 90 percent of theoretical value are favorable for evaluating the transport of cesium ions in these types of structures.

- For gas-liquid inclusions, the development of numerical algorithms for the spherical liquid inclusion with a centrally positioned spherical gas bubble is complete for the decoupled temperature effects.

SITE

- In the Permian Basin, portions of the study area meeting preliminary screening specifications were identified and recommended for further investigation. The Texas Bureau of Economic Geology completed detailed stratigraphic cross sections of the Upper Permian, Triassic, and Tertiary strata in the Palo Duro Basin.

- The salt dome site characterization planning effort centered on meetings in Texas, Louisiana, and Mississippi to discuss the key issues of concern. These issues were identified by the states as requiring resolution to allow screening from one to four domes for detailed site characterization.

- In the Paradox Basin, primary effort was directed toward preparing the five-volume area characterization report, laboratory analysis of core samples from the Salt Valley and Gibson Dome boreholes, and re-entry of the existing Kubat hole. Operations at the Kubat hole reached a depth of 3,000 feet.

- Work is being conducted in the Lake Superior region to identify potentially suitable intrusions through a study of existing literature. Argonne National Laboratory continued to integrate and analyze environmental data gathered for a portion of the region. A summary environmental characterization is in the latter stages of preparation.

- Pacific Northwest Laboratory continued gathering baseline environmental data in the Northeast region. Meetings were held with Argonne National Laboratory (performing the Northeast geologic characterization), wherein agreement was reached on the boundaries of the study region.

- Oak Ridge National Laboratory completed gathering about 95 percent of the required environmental baseline data for the Southeast region. Ecosystem, water resources, climatic data, land use, and demographic data bases are complete.

- Laboratory observations of diagenetic alterations of the Conasauga shale suggest that in a HLW repository in shale, the increased temperature may cause the crystallization of chlorite, quartz, and/or calcite in the small tension fracture caused by the excavation, producing a self-healing process that will decrease fracture porosity and permeability.

REPOSITORY

- The salt model pillar studies project tested a series of model pillars under temperature and pressure conditions that would be expected in an actual disposal operation. The results indicate that for each sample there is a high rate of deformation that decreases with time. This decrease in deformation rates is shown to continue to 600 hours. However, in other tests, it has been observed that rates continue to decrease even after several years. These results are in agreement with measurements that have been made in various salt mines.

- The post-test evaluation activities of the Avery Island Sites A and B heater tests included the removal of the Site B heater and sleeve assemblies and continued data-gathering activities at both sites. Also, the Site NB (natural brine) brine movement experiment was terminated, the Site SB (synthetic brine) overcore was completed at a final depth of 19 feet 7 inches, and two of the Phase II accelerated borehole closure experiments were activated.

- The convective heat transfer in room and pillar geometries project made significant progress in obtaining a correlation for fully developed Nusselt numbers in a rectangular duct with aspect ratio 1.0. Reynolds numbers ranged from 98,300 to 32,000. In addition, three regions were identified in the rectangular duct: laminar, transition, and fully developed turbulent flow. The thermal and hydrodynamic entry length has been determined for the above ranges of Reynolds numbers.

- The main activity of the analysis of flow-through fractured crystalline rock project was to develop the basic statistical parameters needed to characterize the fracture system at Stripa. This included calculating the true strikes and dips of the fractures from the relative orientations of fractures mapped in the drill core.

- In the project on rock behavior under elevated pressure and temperature, calibration of the thermal conductivity measurement was achieved with the completion of the run on the reference standard of GE 124 fused silica. Data were taken to 50 MPa and 200 C, as planned. Also, permeability tests in Units I and II on intact samples of Climax Stock quartz monzonite and Stripa granite were nearly completed.

- A draft report on numerical simulations of earthquake effects on tunnels for generic nuclear waste repositories, by Science Applications, was completed. The objectives of this generic study are to use numerical modeling techniques to determine under what conditions seismic waves generated by an earthquake might cause instability to an underground opening, or cause fracturing and joint movement that would lead to an increase in the permeability of the rock mass.

- In repository sealing work, the results from the plug flow test have been analyzed and are in good agreement with the results obtained from the Bell Canyon borehole plug test. The dye penetrant added to the water during the flow test clearly indicated that the flow path was at the cement-rock interface.

- NWTS repository equipment development activities included revision of the technology development plan for NWTS repository equipment, preparation of a draft repository equipment test plan, and preparation of draft Statements of Work for equipment technology development.

REGULATORY AND INSTITUTIONAL

- Development of a NEPA implementation strategy in conformance with the current NWTS program was intensified during the report period. Draft strategies were developed for consideration by NWTS, and a workshop was held to evaluate draft strategies and develop consensus on the most favorable approach.

TEST FACILITIES AND EXCAVATIONS

- In the alternative geology test facility mine screening project, computer programs for screening and ranking were completed. A list of 66 mines meeting the general identification criteria was developed. The screened data base was supplemented by additional data from various sources.

PUBLIC INFORMATION PROGRAM

MAJOR PUBLIC INFORMATION EVENTS OF THE QUARTER

Significant meetings and briefings in support of the ONWI program continued during April to June in several states. These meetings and briefings included:

- A Conference on Salt Dome Storage of Nuclear Waste in Louisiana in Baton Rouge, on April 7, followed by a program briefing for Mississippi state officials in Jackson, April 8.
- A briefing for Rhode Island state officials in Providence, April 28.
- A Legislative Forum on nuclear waste isolation at the University of Southern Mississippi, Hattiesburg, June 15.
- A briefing of the Utah Nuclear Waste Repository Task Force in Salt Lake City, June 18.
- A briefing for New York state officials in Albany, June 24.

Major information activities during the quarter included:

- Providing drill site fact sheets and weatherproof containers for drill sites in Donley and Oldham Counties, Texas, and the ER-1 and Kubat sites in the Paradox Basin, Utah. The fact sheets are posted at the drill sites to provide information to visitors about activities.

- Mailing a news release on June 3 to Utah media personnel announcing the resumption of drilling activities in the Elk Ridge area of the Paradox Basin. Preparing a news release distributed May 29 by DOE/Dallas announcing drilling activities in the Permian Basin.
- Completing work on a special briefing package for use by DOE and USGS in Basin and Range Province (Province 9) states. Also completing work on a Mississippi briefing package and background information for Mississippi communication media.
- Development of a proposed news release, background material, and suggested mailing list to facilitate information to the media on the Evaluation of Area Studies of the U.S. Gulf Coast Salt Dome Basins (ONWI-109).

MAJOR REPORTS PUBLISHED DURING THE QUARTER

DP-1555	Parametric Study of Geohydrologic Performance Characteristics for Geologic Waste Repositories
DP-1559	Executive Summary - Review of Potential Host Rocks for Radioactive Waste Disposal in the Southeastern United States
DP-1561	Review of Potential Host Rocks for Radioactive Waste Disposal in the Piedmont Province of Virginia and Maryland
DP-1562	Review of Potential Host Rocks for Radioactive Waste Disposal in the Piedmont Province of North Carolina
DP-1563	Review of Potential Host Rocks for Radioactive Waste Disposal in the Piedmont Province of South Carolina
DP-1564	Review of Potential Host Rocks for Radioactive Waste Disposal in the Piedmont Province of Georgia
DP-1567	Review of Potential Host Rocks for Radioactive Waste Disposal in the Southeast United States - Southern Piedmont Subregion
DP-1568	Review of Potential Host Rocks for Radioactive Waste Disposal in the Southeast United States - Southeastern Coastal Plain Subregion
DP-1569	Review of Potential Host Rocks for Radioactive Waste Disposal in the Southeast United States - Triassic Basin Subregion
LBL-11180/SAC-30	The Effect of Radon Transport in Groundwater Upon Gamma Ray Borehole Logs
LBL-11477/SAC-29	Thermal and Thermomechanical Data From In Situ Heater Experiments at Stripa

ONWI-13	Estimated Environmental Effects of Deep Drilling
ONWI-30	Evaluation of Cement Borehole Plug Longevity
ONWI-75	Subsurface Waste Handling Equipment Criteria and Specification Development
ONWI-105	Estimated Environmental Effects of Geologic and Geophysical Exploratory Activities
ONWI-203	Retrievability: Technical Considerations
ONWI-218	Recommended Waste Handling Operations and Equipment
ORNL/TM-7201	Expected Environments in High-Level Nuclear Waste and Spent Fuel Repositories in Salt
ORNL/TM-7597	Expected Environments for a Defense High-Level Waste Repository in Salt
ORNL/ENG/TM-31	Thermal Analysis Supporting the Design of the Avery Island Field Experiments
PNL-3542	Geologic Simulation Model for a Hypothetical Site in Basalts of the Columbia Plateau
PNL-3789	Geostatistical Modeling of Pore Velocity
PNL-3817	Use of Geohydrologic Response Functions in the Assessment of Deep Nuclear Waste Repositories
SAND81-1204C	Summary of Research and Development Activities Related to the US/FRG Cooperative Program on Nuclear Waste Management
SAND81-1232	Analysis of Data from Line Source Thermal Conductivity Measurements Taken in Situ in Dome Salt at the Avery Island Mine

TECHNICAL PROGRESS REPORTS

In this section the progress reports of the programs in the various waste management technologies are presented according to the organization of the Work Breakdown Structure (WBS). Each report carries a WBS number for the convenience of the reader. The content of the second level of the WBS follows:

WBS 1.1 Systems. These reports deal with systems analysis, socio-economic assessment, alternative disposal concepts, and performance assessment.

WBS 1.2 Waste Package. These reports consist of studies on performance measures, waste forms, barrier materials, the design and testing of waste packages, and performance evaluation through modeling, demonstration testing, and natural experiments.

WBS 1.3 Site. These reports deal with the earth sciences of geophysics, geochemistry, and transport properties, and with geologic, hydrologic, and environmental characterization of sites that provide natural barriers in salt, granite, and shale.

WBS 1.4 Repository. The repository reports involve studies to build a data base; equipment, instrument, and seal development; repository engineering and conceptual design; and performance evaluation.

WBS 1.5 Regulatory and Institutional. The work reported in this area concerns the regulatory, social, and political acceptance of the proposed repository system.

WBS 1.6 Test Facilities and Excavations. This area is concerned with facilities in both salt and alternative media which will eventually be used for laboratory and in situ testing of the relationships among the package, repository, and site.

SUMMARY

1.1 SYSTEMS

The scope of the Systems Task covers the systems analyses, socioeconomic assessments, and performance assessments of the entire waste isolation system. Also covered in this task are investigations of alternative disposal concepts for nuclear waste disposal. The prime objective of this task is to identify the options available to resolve the problem of waste isolation and to make suitable choices among the alternatives by broad ranging, multidisciplinary analyses.

A draft analysis of the potential impact of intermediate scale facilities for nuclear waste was prepared. Preparation of a topical report on the management by decision (MBD) technique continued.

A computer model was developed to assist in preparing preliminary estimates of repository costs and the cost impact of design changes. The model uses cost data from numerous detailed architectural and engineering estimates as a basis. The model can be used to develop cash flows and total costs. Costs are organized into ten cost centers.

Work continued on the impact on the user fee schedule of a nuclear waste isolation facility of adopting a system of payments to the local government in lieu of tax payments. Research on establishing a framework for evaluating the utility of incentive systems for siting waste facilities has accelerated, and preliminary criteria are under development.

Conceptual flowsheets were prepared for (a) removing technetium from high-level liquid waste, (b) removing iodine from silver zeolite and converting it to lead iodide, and (c) removing 95 percent of cesium and strontium from high-level liquid waste. Waste form and waste process compatibility with space disposal technology was examined, and thermal analysis of the repository in bedded salt (Paradox Basin) was completed.

Significant progress was made in the laboratory research on the closure of fractures under conditions of high temperature and pressure. New methods of measuring the extent of fracture closure are now being developed. The second component of the very deep hole laboratory research is a physical model study of the failure and collapse of boreholes at great depth. The fabrication of the sample molds had been completed, and the first samples are formed. A volume measuring system for monitoring the sample borehole under pressure has been completed and is undergoing testing.

The draft of the report on the uncertainties of sensitivities in the performance of geologic nuclear waste isolation systems was finalized. In addition to the ongoing systems uncertainty analysis, a short-term study on intermediate scale facilities was initiated and completed this quarter.

The AEGIS evaluation of EPA standard 40 CFR 191 and supporting documentation was compiled from technical reviews and will be included with ONWI GETOUT runs in the DOE response to the proposed standard. Five-hundred "final" Monte Carlo simulations were performed with the Geologic Simulation Model, along with several smaller sensitivity analyses, following finalization of input data. Preparation of a draft final report is in progress, as is the summary input to the basalt reference site initial assessment (RSIA) report. Documentation of the DITTY1 dose code approached completion.

Draft detailed performance specifications were completed for each of the models required in the SCEPTER technology and are being reviewed. The draft documentation was completed on the pilot version of the Far-Field State Model, which is a conversion of the PNL Geologic Simulation Model to a large computer. Design specifications for the Waste Package Subsystem Model were drafted and reviewed and are being modified.

The development of a ground-water flow model for fractured media has been completed, and analytical support to the LLNL hydrology tests continued. The SCEPTER approach to uncertainty analysis was outlined, and a report was begun describing the approach and rationale. Subcontractor contributions to the NWTS Performance Assessment Plan were completed and submitted to ONWI for integration into the plan.

The two-dimensional analytical transport code, UCBNE 25, which predicts radionuclide concentration in steady ground-water flows, was used for predicting the far-field migration of radionuclides released from waste packages at the WIPP site, New Mexico, and the BWIP site, Hanford, Washington. Two other models for the steady state mass transfer from a glass canister into an unbounded saturated porous medium have been investigated. A code for radionuclide transport through a fractured rock has been modified to include decay chains.

During this quarter, a method was developed which yields physical insight into leach rate trends while minimizing the required mathematical effort. A necessary condition, at this time, is the time-invariance of the parameters used to represent the mechanisms controlling waste form leaching.

WBS 1.1.2

PROJECT: Waste Isolation Program Evaluation Assistance

PRINCIPAL INVESTIGATOR: Lawrence Livermore National Laboratory (R. C. Maninger)

ONWI PROJECT MANAGER: J. D. Waddell

OBJECTIVE

The objective of this project is to enhance the ONWI capability for NWTS program planning. Specifically, the project shall:

- Design a methodology for representing the planned structure of the research and development activities and results of the NWTS program.
- Develop a methodology for coalescing the data being generated by the NWTS program and presenting the results in a form most useful to decision makers.

PROGRESS REPORTED PREVIOUSLY

Two sets of management by decision (MBD) charts were prepared to represent major parts of the NWTS program from two different perspectives. This illustrated the importance of having well-defined purposes for constructing MBD charts and of using no more graphic detail than necessary to show essential elements and their contextual relations for each purpose. Adjacency matrices were also introduced as another way of showing contextual relations among elements of an MBD representation of a plan. The matrices complement the charts and are useful as aids in preparing charts.

ACTIVITIES DURING THE REPORTING PERIOD

The principal activities during this period were devoted to completing the analysis of the potential impact of intermediate scale facilities for nuclear waste, preparing an annual project impact report, and starting preparation of a topical report on MBD. This report is intended to bring together into a single document all of the essential concepts of managing by decisions that have been used to date in this project for the NWTS program.

FUTURE ACTIVITIES

Revisions to the draft report will be made, and the final report will be issued.

Actions of the 97th Congress on nuclear waste management issues will be monitored and analyzed by MBD methods to identify potential impacts on the NWTS program.

WBS 1.1.2

PROJECT: Disposal Charge Analysis

PRINCIPAL INVESTIGATOR: Battelle Pacific Northwest Laboratories (L. L. Clark)

ONWI PROJECT MANAGER: J. D. Waddell

OBJECTIVE

The objective of this program is to determine the sensitivity of the disposal charge, including that of defense wastes, to geologic and institutional factors.

PROGRESS REPORTED PREVIOUSLY

This project began June 1980 with an analysis of the impact on disposal charges of storing defense wastes in commercial spent fuel repositories. The effect of various institutional factors on charges was analyzed and data collection was initiated for an analysis of the effect of repository media on disposal costs.

A repository cost model was developed to facilitate the analysis of costs of mined geologic repositories in alternative media. The model was completed and benchmarked to verify its accuracy. A series of cases is now being run to analyze the cost sensitivity of media-dependent variables.

ACTIVITIES DURING THE REPORTING PERIOD

The repository cost model, RECON, was developed and completed. The model simulates ten cost centers in a repository: facility construction and equipment, shaft development, mine development and mined rock logistics, prestartup costs, waste receiving and packaging, other surface operations, underground waste handling, utilities, shaft sealing and decommissioning, and cost allocations by waste type. The model develops cash flow requirements based on cost streams from the above cost centers and calculates both total and levelized unit costs for up to five repositories in a single case.

The cost model was benchmarked using cost data from the draft Conceptual Reference Repository Design (CRRD) report for a repository in domed salt. The RECON estimates were $4.5 billion, or within 5 percent of the CRRD estimate of $4.7 billion.

Reference cases were then developed for generic spent fuel repositories in salt, granite, basalt, and tuff. The reference cases assume that 1 PWR or 2 BWR elements are packaged in 0.4 m diameter steel canisters with a 0.64 cm titanium skin. These are emplaced in holes with a carbon steel liner surrounded by a 0.3 m annulus of bentonite. The reference packages are the same for each medium. All other parameters which were not readily identifiable as being media-dependent were also held constant for each media. Media-dependent variables included rock density, unit mining and rock handling costs, unit backfilling costs, hole spacing, extraction ratio, shaft depths, room dimensions, hole drilling costs and limiting thermal desnity criteria. Costs for the reference repositories are summarized in Table 1.

The driving factors in the cost estimates (and the reason that the estimates in Table 1 differ significantly from the CRRD estimate) are the packaging and hole lining concepts, as shown in the unit cost breakdown in Table 2. This table indicates that for repositories which are similar in all nonmedia-related aspects, salt would be the least expensive medium due principally to lower hole drilling costs, and to a lesser extent lower mining costs.

FUTURE ACTIVITIES

In the next quarter the sensitivity of costs to changes in media-dependent variables will be examined using the RECON model, and least cost scenarios will be defined for each medium. The results will be published in a topical report.

Table 1. Reference Repository Costs in Alternative Media.

	Medium			
	Salt	Granite	Basalt	Tuff
Total Cost, Billions of 1981 Dollars	10.4	14.2	14.5	13.2
Unit Cost of Spent Fuel Disposal, $/kg Heavy Metal	112	140	142	128

Table 2. Unit Cost Analysis for Reference Case Repositories, $/kg Heavy Metal.

	Medium			
	Salt	Granite	Basalt	Tuff
Facility Construction and Equipment	14	13	13	13
Shafts	2	2	2	1
Mining	4	7	7	5
Waste Operations Labor	11	11	11	11
Packaging	48	48	48	48
Hole Preparation and Lining	29	55	57	46
Other	4	4	4	4
TOTAL	112	140	142	128

WBS 1.1.3

PROJECT: Institutional Arrangements for Radioactive Waste Siting

PRINCIPAL INVESTIGATOR: Oak Ridge National Laboratory (E. Peelle)

ONWI PROJECT MANAGER: J. R. Finley

OBJECTIVE

The objective of this work is to assess the impacts of nuclear waste isolation facilities on local and state host areas and to design siting arrangements which are acceptable to local interests. The design and testing of possible incentive arrangements for siting a hazardous waste facility must, therefore, include an integration of the economic, institutional, and public participation factors into each alternative considered.

The goal is to develop a range of evaluated options to include in the consultation and other siting processes including incentives; compensation mechanisms for risk, damages, and long-term land commitment; state and local participation; local verification and monitoring; and mediated negotiation.

PROGRESS REPORTED PREVIOUSLY

Beginning in the last quarter of FY 80, an evaluation was made of the payments-in-lieu-of-taxes (PILOT) mechanism for three atomic communities and its possible application to nuclear waste disposal siting. This work is continuing, as is the more general review of existing institutional arrangements and incentives for siting waste handling facilities.

The report on fiscal interactions between local governments and federally owned waste isolation facilities has been completed. This analysis of transfer payments from a federally owned facility to the local government affected by the facility stresses the distinction between the compensation of costs and the provision of incentives. Unless a community can be shown to reach a higher level of satisfaction, under a rather strict interpretation of satisfaction, it will have no incentive to encourage the siting of a facility, whether or not the direct costs associated with the facility are compensated. Despite this fact, it should be possible to design an intergovernmental revenue system that does provide incentives.

ACTIVITIES DURING THE REPORTING PERIOD

Work continued on the impact on the user fee schedule of a nuclear waste isolation facility of adopting a system of payments to the local government in lieu of tax payments. It is recognized that wide variations in local government service levels and revenue systems preclude accurately forecasting the local fiscal impacts of a nuclear waste disposal facility. This work attempts to place bounds on the range of these impacts and relates these impacts to the changes in the user fees that would be necessary to finance local services. The need for PILOT arises because federal ownership will render the waste isolation facility exempt from local taxation. Although there are many valid reasons for a tax-exempt activity to make payments to local governments, the present concern is to overcome disincentives for localities to host nuclear waste isolation facilities. Communities accept many government installations, such as post offices, armories, and national monuments, under a tax-exempt status because local residents perceive either some benefits or, at a minimum, no costs from their presence. Hazardous materials handling facilities, such as a high-level nuclear waste isolation facility, are quite likely to be evaluated by locals as detrimental. Efforts by the federal government to overcome this perception will be necessary if successful siting is to take place.

The diversity of fiscal behavior characterizing local governments in the United States and the range of options available for developing fiscal relationships between these governments and a nuclear waste isolation facility are difficult characteristics to assimilate into forecasting the implications for localities of siting a waste isolation facility in absolute terms. However, the calculations are sufficient to argue both the need for a payment plan of some sort and the minimal impact such payments would have on user fees. Estimates of the levels that payments to communities might take have been made, under the assumption that payments are based on the property tax liability that would be levied if the facility were taxable. To place this in perspective, revenue and expenditure data for communities of different sizes have been examined. Estimates of the impact of these payments on the facility's user-fee schedules indicate that user fees might increase from 8 to 11 percent. To prepare these calculations, a method for calculating user fees derived from past research by the Office of Nuclear Waste Isolation Program is adopted as a starting point, and the impacts of a number of options under the assumed payment plan are explored. Although these calculations are admittedly crude, they likely overstate the percent of impact, because some facility-related costs were omitted and because payments as high as those postulated are not likely to be politically feasible. Moreover, from a cost perspective, there is little to be gained from attempting to limit payments over time.

Research on establishing a framework for evaluating the utility of incentive systems for siting waste facilities has accelerated, and preliminary criteria are under development. The initial criteria have been identified and grouped according to whether they relate most directly to the incentive, the local population, or to what happens when the incentive is applied to a local situation. Types of incentives have been classified according to the needs they are to fill, and an initial set of rules for use of the criteria is complete.

FUTURE ACTIVITIES

During the coming quarter, the research on preliminary criteria for the evaluation of incentives for siting waste facilities will be completed and reported, with the attendant instructions for their use and applicability to the types of incentives needed to fill varying needs of host communities. Development of incentive options and validation of the preliminary criteria will then be pursued along the lines of the analytical framework established.

WBS 1.1.4

PROJECT: Waste Mix for Space Disposal

PRINCIPAL INVESTIGATOR: Battelle Pacific Northwest Laboratories (R. F. McCallum)

ONWI PROJECT MANAGER: R. E. Best

OBJECTIVE

The objective is to identify the benefits to a waste management system (using a geologic repository as the disposal technology) that result from removing candidate isotopes from the waste stream and disposing them in space.

PROGRESS REPORTED PREVIOUSLY

Scoping efforts on all tasks were begun.

A literature search of documents which identify "hazardous isotopes" or "isotopes of concern in terms of repository safety" was begun.

ACTIVITIES DURING THE REPORTING PERIOD

Conceptual flowsheets were prepared for (a) removing technetium from high-level liquid waste, (b) removing iodine from silver zeolite and converting it to lead iodide, and (c) removing 95 percent of cesium and strontium from high-level liquid waste.

Waste form and waste process compatibility with space disposal technology was examined.

Thermal analysis of the repository in bedded salt (Paradox Basin) was completed.

FUTURE ACTIVITIES

Project staff, in conjunction with Boeing, will be finalizing key waste form parameters (i.e., waste loading, billet size).

WBS 1.1.4

PROJECT: Very Deep Hole Geosciences

PRINCIPAL INVESTIGATOR: Lawrence Berkeley Laboratory (LBL) (L. Cohen and T. Doe)

ONWI PROJECT MANAGER: R. E. Best

OBJECTIVE

The FY 81 objectives are to (1) investigate the question of fracture closure with depth, (2) determine what mechanisms contribute to borehole failure at depth, and (3) begin developing numerical models of heating, stress, and fluid flow around a deep hole repository.

PROGRESS REPORTED PREVIOUSLY

This project began in FY 80. Initial results of the fracture closure study indicated unreasonably high contact areas at modest normal stresses.

ACTIVITIES DURING THE REPORTING PERIOD

Significant progress was made in the laboratory research on the closure of fractures under conditions of high temperature and pressure. Previous experimental difficulties were resolved, and several granite samples were tested. By monitoring the rejection of water from a fracture under stress, together with new interpretive techniques, a reasonable contact area of 20 percent at 200 bars stress has been indicated.

New methods of measuring the extent of fracture closure are being developed. Various thin plastic films have been sandwiched in stressed fractures, with the resulting contact areas appearing as microfractures in the film. These microfractures reduce the transparency of the film, which then can be measured and digitized with an optical densitometer.

The second component of the very deep hole laboratory research is a physical model study of the failure and collapse of boreholes at great depth. The model uses a plaster-sand mixture in tests at moderate pressure to simulate the behavior of competent rocks under more extreme conditions. The fabrication of the sample molds has been completed, and the first samples are formed. A volume measuring system for monitoring the sample borehole under pressure has been completed and is undergoing testing.

FUTURE ACTIVITIES

A computer modeling study of fracture closure and convective fluid flow around a deep hole repository will be undertaken. The thin-film study of fracture closure will progress to more realistic deep hole stress levels (about 2,000 bars). Theoretical models will be developed to explain the results of both the water-rejection and the thin-film experiments. The borehole failure simulation experiment will be completed. By the end of the quarter, all activities will have ceased due to the termination of the NWTS deep hole waste isolation program.

WBS 1.1.5

PROJECT: Systems Characteristics Analysis

PRINCIPAL INVESTIGATOR: Lawrence Livermore National Laboratory (W. G. Sutcliffe)

ONWI PROJECT MANAGER: J. D. Waddell

OBJECTIVE

The objective of this project is to develop information on how the uncertainties about engineered and natural systems affect the uncertainty of long-term performance for nuclear waste repositories. The purpose for developing this information is to provide background information which ONWI can use in formulating R&D plans. This work provides a systems analysis perspective.

The primary objective is to identify the uncertainties dominating the uncertainty about the performance of a system. In particular, the conditions under which various subsystems and parameters dominate will be identified. Also, the potential differences between waste forms, geologic media, and site characteristics and how these differences affect the assessed performance of the system will be considered.

The scope of the work has been limited to post-closure analysis of nuclear waste migration via ground-water flow.

PROGRESS REPORTED PREVIOUSLY

Since this project was initiated in May 1980, the work has concentrated on developing and applying systems models in probabilistic analysis of geologic waste isolation systems. Simple models were used to characterize the waste form and package, repository site, and regional aquifer subsystems. The methods of analysis and computation were presented, along with examples of quantitative results. The computations were nearly completed, and the final report for this study was being drafted.

ACTIVITIES DURING THE REPORTING PERIOD

Uncertainty Analysis

The analyses, result interpretations, and drawing of conclusions for the report have been completed. The draft of the report on the uncertainties of sensitivities in the performance of geologic nuclear waste isolation systems was finalized.

The analyses consisted of (1) a parametric analysis of the overall systems model, and (2) an analysis of a hypothetical system using more detailed models of the subsystems. The purposes were to (1) investigate the relative effects of the uncertainty about each model parameter, and (2) determine the general characteristics of systems which can be represented by a point source and series pathway model.

Both deterministic and probabilistic parametric analyses were conducted over a range of parameter values large enough to encompass significantly different sites in different media, and different waste forms and packages. These results are applicable in general to isolation systems which can be represented by the model. The parameters of the high-level model were the transit time and waste pulse spread for the system, and the dissolution time. The systems analysis considered more fundamental parameters of the waste migration pathways, treating these parameters probabilistically. The analysis demonstrated the contribution of each subsystem to overall system performance.

Detailed conclusions were drawn about the system model parameters, relative to the particular systems and scenarios that were analyzed. In addition, some of the general conclusions are summarized below:

- Global parametric analysis is more informative and applicable than local sensitivity analysis.

- The individual contributions of each of the multiple barriers (subsystems) are often additive rather than multiplicative.
- The uncertainties associated with the weaker subsystems (for a given scenario) have little effect on the uncertainty in system performance.

Intermediate Scale Facility (ISF) Study

In addition to the ongoing systems uncertainty analysis, a short-term study on intermediate scale facilities was initiated and completed this quarter. In particular, the need for information about repositories before they are designed, constructed, and operated led to the suggestion that a repository test and training facility be constructed.

FUTURE ACTIVITIES

Revisions to the draft report will be made, and the final report will be issued.

WBS 1.1.5

PROJECT: Assessment of Effectiveness of Geologic Isolation Systems (AEGIS)

PRINCIPAL INVESTIGATOR: Pacific Northwest Laboratory (F. H. Dove)

ONWI PROJECT MANAGER: G. E. Raines

OBJECTIVE

The overall objectives of the Assessment of Effectiveness of Geologic Isolation Systems (AEGIS) program are to: (1) develop the capabilities needed to assess the postclosure safety of geologic repositories; (2) demonstrate the assessment capabilities by performing analyses of reference sites; (3) apply the assessment methodology to assist the National Waste Terminal Storage program in site selection and waste package and repository design; and (4) perform repository site analyses responsive to the time schedule and to the level of sophistication required to meet the licensing needs of the National Waste Terminal Storage program.

PROGRESS REPORTED PREVIOUSLY

The Geologic Simulation Model was used in the Monte Carlo mode to generate a 200-simulation analysis for inclusion in the reference site initial assessment (RSIA) draft for basalt. The simulations helped delineate those areas of model data that still need attention and also gave some useful although not quantitatively reliable results.

Geostatistical modeling of ground-water pore velocity within a region of the Hanford reservation was completed. A two-dimensional analytic solution was calculated to check the stochastic transport code currently under development.

The DITTY1 code was used to calculate population doses from five scenarios applied to a high-level waste repository as a comparison with EPA criteria. The results of the well water scenario match the EPA criteria of 10 health effects better than the other four scenarios studied.

ACTIVITIES DURING THE REPORTING PERIOD

The topical report, Use of Geohydrologic Response Functions in the Assessment of Deep Nuclear Waste Repositories (Nelson, 1981), has been published.

Two complementary approaches to the hydraulic conductivity inverse problem have been developed. A direct circuit integral method based upon a mathematical statement of mass conservation yields a global solution to the inverse problem without calculating path lines. Mathematical investigations of this method indicate that its continuity with respect to perturbation in input data is improved over previous methods of similar complexity. The second technique is based upon a variational principle and is expected to behave even more smoothly with respect to input noise. The variational technique depends upon a good starting approximation to the conductivity. This initial approximation will be provided by the circuit integral method.

Work accomplished in contaminant transport under uncertainty includes the following:

- The two computer codes developed have been named SCDE1D and SCDE2D. The last two characters distinguish the one-dimensional and two-dimensional versions. The other four characters stand for Stochastic Convection Differential Equation.
- SCDE1D and SCDE2D have been compared by applying them to a one-dimensional problem for which an approximate analytical solution is known. The comparison is favorable.
- SCDE2D has been applied to a two-dimensional problem for which an approximate analytical solution is known. The results are encouraging.

- SCDE2D has been applied to the Hanford data using covariance functions obtained through Kriging techniques.
- The final draft of a document describing the numerical procedure and application of SCDE2D to the two-dimensional problem is almost completed.

The basalt RSIA draft reflects AEGIS interpretation of an extensive data base, including recent data.

Computer files associated with the basalt RSIA calculations have been backed up for long-term preservation.

The AEGIS evaluation of EPA standard 40 CFR 191 and supporting documentation was compiled from technical reviews and will be incorporated into the DOE response to the proposed standard. The evaluation concluded with the strong recommendation that the DOE reject the standard as proposed.

Five-hundred "final" Monte Carlo simulations were performed with the Geologic Simulation Model, along with several smaller sensitivity analyses, following finalization of input data. Preparation of a draft final report is in progress, as is the summary input to the basalt RSIA report.

Documentation of the DITTY1 dose code approached completion.

A new task, data analysis, will concentrate on evaluating the quality and completeness of hydrologic data for potential repositories in domal and bedded salts of the Gulf Coast, Paradox Basin, and Permian Basin.

FUTURE ACTIVITIES

The documentation of fracture flow analysis will continue.

Analysis of data from the GSM Monte Carlo analyses will be completed, and the report on results of the Geologic Simulation Model for a hypothetical site in the Columbia Plateau will be prepared.

In the data analysis task, both the top of the fresh water and the base of freshwater potentiometric surfaces will be estimated for the salt dome region. Between 25 and 50 data points are available to estimate the top of the fresh water. More data may be available from the USGS, perhaps several hundred points.

REFERENCE

Nelson, R. W., 1981. Use of Geohydrologic Response Functions in the Assessment of Deep Nuclear Waste Repositories, PNL-3817, Pacific Northwest Laboratory, Richland, WA.

WBS 1.1.5

PROJECT: Systematic Comprehensive Evaluation of Performance and Total Effectiveness of Repositories (SCEPTER)

PRINCIPAL INVESTIGATOR: INTERA Environmental Consultants, Inc. (R. E. Wilems)

ONWI PROJECT MANAGER: H. C. Burkholder

OBJECTIVE

The objective of this program is to integrate, develop, and apply modeling technology to evaluate the effectiveness of nuclear waste isolation systems in preventing adverse radiological effects to present and future human beings and their environments. The technology will be used to support technology development, site evaluation, repository design, waste package design, and qualification and licensing activities of the NWTS program.

PROGRESS REPORTED PREVIOUSLY

The SCEPTER contract began in January, 1980. Work during the first fiscal year concentrated on three fundamental areas: (1) program planning, (2) defining the scope of the modeling technology required to support the NWTS program, and (3) reviewing and evaluating the available technology. Through these activities, details of the program were structured, models that needed to be acquired or developed were identified, and integration concepts were defined. In the far-field task, selected geosphere, biosphere, and far-field state models were acquired, converted, and integrated, and they have undergone initial operational testing. In the near-field task (repository and waste package), acquisition and conversion of selected models have begun. Draft performance specifications were prepared, and the review and evaluation of existing technology was completed.

In addition, the first development activity under the SCEPTER program is proceeding: the development of a dual porosity-discrete fracture flow model. The first application activity for the SCEPTER modeling technology was identified: an independent assessment of the LLNL and LANL hydrology and nuclide migration tests at the Nevada Test Site.

Initial steps were taken to define SCEPTER's approach to uncertainty analysis.

ACTIVITIES DURING THE REPORTING PERIOD

Most important to the SCEPTER program at this stage are the definition, acquisition, conversion, integration, and operational testing of existing model technology. Specific progress during the quarter includes the following.

Draft detailed performance specifications were completed for each of the models required in the SCEPTER technology and are being reviewed.

The draft documentation was completed on the pilot version of the Far-Field State Model, which is a conversion of the PNL Geologic Simulation Model to a large computer. Integration of appropriate far-field process models into a Site Subsystem Model is progressing. This subsystem model will include a simple network flow model (being developed), nuclide transport (modified GETOUT), and biosphere transport (PABLM), which will be coupled to the Far-Field State Model and a simplistic Repository Model. In addition, detailed operational comparisons were conducted on various ground-water flow codes, and SWENT or USGS3D and MMT are suggested for inclusion in the SCEPTER technology package. Similar comparisons of various biosphere codes resulted in the recommendation of including PABLM and DACRIN in the SCEPTER technology.

Design specifications for the Waste Package Subsystem Model were drafted and reviewed and are being modified. Similarly, draft design specifications were begun for the Repository Subsystem Model. Near-field model acquisition, conversion, and modification continued. All desired waste package models have been acquired and converted; modification and integration have begun. Only 75 percent of the repository models are acquired or developed, while one other is being developed and the others need yet to be attained. Modification of the acquired codes has begun, but integration is lagging.

The development of a ground-water flow model for fractured media has been completed, but the documentation is not complete.

Analytical support to the LLNL hydrology tests continued. Initial interpretations indicated that the test fracture was only partially saturated and that additional hydrologic capacitance also exists in the test system.

The SCEPTER approach to uncertainty analysis was outlined and a report was begun describing the approach and rationale.

Contributions to the NWTS Performance Assessment Plan were completed and submitted for review.

FUTURE ACTIVITIES

Activities scheduled for the next quarter include:

- Begin modification of Far-Field State Model to handle salt sites
- Complete an initial integrated Site Subsystem Model
- Complete an integrated Waste Package Subsystem Model
- Begin integration of Repository Subsystem Models
- Complete documentation of ground-water flow model for fractured media
- Complete Uncertainty Analysis Report
- Complete analytical support to LLNL hydrology test
- Perform pretest calculations for LLNL migration test
- Accomplish initial planning for FY 82, including major technology integration and documentation milestones and support for evaluating three potential salt sites.

WBS 1.1.5

PROJECT: Analysis of Radionuclide Migration in Geologic Media

PRINCIPAL INVESTIGATOR: University of California at Berkeley (T. H. Pigford)

ONWI PROJECT MANAGER: H. C. Burkholder

OBJECTIVE

The objectives are to develop analytical solutions and to make diagnostic calculations of the migration of radionuclides through geologic media. The exact results of these calculations can be used as benchmark checks against numerical computer codes. The solutions are used to predict the space-time-dependent concentrations of the effects of phenomena not previously considered or not previously well understood in the modeling of radionuclide transport.

PROGRESS REPORTED PREVIOUSLY

The details of progress for FY 80 appear in the report, Migration of Radionuclides Through Sorbing Media: Analytical Solutions - II, LBL-11616. This report has been issued.

The final report for FY 79, Migration of Radionuclides Through Sorbing Media: Analytical Solutions - I, LBL-10500, was completed.

ACTIVITIES DURING THE REPORTING PERIOD

Radionuclide Transport in Two-Dimensional Water Flow

The computer code UCBNE 25 predicts radionuclide concentrations in steady two-dimensional ground-water flows, based upon the analytical theory presented in Chapter 5 of Pigford et al (1980). The decay chain is of arbitrary length. Radionuclide discharge rates, as well as cumulative discharge of any nuclide in the waste into the biosphere, can be evaluated.

The ground-water flow is represented by Darcy's law, dispersion effects are neglected, sorption reactions are in equilibrium, and there is no solubility limit. Water and soil densities are constant. The hydraulic conductivity is isotropic and variable with position.

The solution to the two-dimensional radionuclide transport equation is analytical and nonrecursive, requiring very little computing time. Besides giving the nuclide concentrations, the code also provides a graphical output of the ground-water potential and stream functions in the contaminated region and a (three-dimensional) surface representation of the potential function. The discharge rates and cumulative discharge rates are also computed.

Two methods are used to construct the ground-water potentiometric function characterizing the flow which governs the radionuclide transport:

1. Analytical expressions representing the superposition of a number of point sinks and point sources can be used to simulate hydrologic flow fields of arbitrary complexity.
2. A given number of piezometric field data can be used to construct the potential function by fitting the field data with the help of a cubic spline of minimum curvature.

The two-dimensional analytical transport code is demonstrated for the far-field migration of radionuclides released from waste packages at the WIPP site, New Mexico, and the BWIPP site, Hanford, Washington. Hydrologic data for both sites were reviewed. Piezometric data, as well as parameters for various aquifers surrounding the repository, were estimated. Using these data in the code UCBNE 25, the contaminated regions for some of the most hazardous nuclides (e.g., ^{129}I, ^{226}Ra) were determined for different times after leaching started.

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The times of arrival of these nuclides at the biosphere were determined. In addition, the discharge rate of ^{129}I and ^{226}Ra, and their cumulative discharges to the biosphere, were also calculated.

Dissolution Models for Waste-Glass Canisters

Mass Transfer into the Exterior Liquid. Two models of the steady state mass transfer from a glass canister into an unbounded saturated porous medium have been investigated. In the first model, the exterior mass transfer is due only to molecular diffusion within the porous medium. In the second model, the exterior mass transfer is due to the combined effects of molecular diffusion and forced convection by a D'Arcy flow. The waste dissolution rate is assumed to be governed by the rate of mass transfer of dissolved silica into the surrounding ground water. An upper limit for this mass transfer rate occurs when the concentration of dissolved silica in liquid at the canister surface is equal to the solubility limit of silica water.

In the model for mass transfer by molecular diffusion, the geometry of the cylindrical canister was approximated by a prolate ellipsoid. The mass loss (gm/day), the average mass flux (gm/cm^2/day), and the leach time (yr) have been calculated.

In the model for combined molecular diffusion and convection, the canister is approximated by a cylinder of infinite length with D'Arcy flow perpendicular to the cylindrical axis. The mass loss, average mass flux, and leach time were computed for a number of different parameter values, such as the ground-water speed. The solubility limit of amorphous silica in water, at a pH of 7 and a temperature of 25 C, is 1.2×10^{-4} gm/cm^3. A diffusion coefficient of SiO_2 of 1×10^{-5} cm^2/sec was chosen. This is typical for molecular diffusion in liquids. Although the effective diffusion coefficient in a porous solid may be considerably smaller, the value for a single-phase liquid is adopted for the present estimate.

Some representative results are shown in Table 1.

Table 1. Results of Mass Transfer into a Liquid.

Model	Ground-Water Speed, m/yr	Mass Flux of Silica, gm/cm^2 day
Molecular Diffusion	0	1.95×10^{-6}
Molecular Diffusion and Convection	1	9.75×10^{-6}
Molecular Diffusion and Convection	10	3.08×10^{-5}

Mass Transfer Within the Solid. In conjunction with the exterior-field mass transport calculations, the mass transport interior to the canister has also been calculated. A single diffusing species, possibly subjected to radioactive decay, is initially uniformly distributed throughout the canister and then diffuses through the solid matrix, which constitutes the canister mass, to its bounding surface, where zero concentration is conservatively assumed. The surface is assumed to regress with a constant speed until such time (the leach time) when the canister mass has vanished. The effect of the regressing surface is to steepen the concentration profile of the diffusing species near the surface, thereby increasing the diffusive flux. This analysis proves that the time-dependent cumulative fractional release, f, of the diffusing species from the canister obeys, to a very close approximation, the experimentally observed relation:

$$f = a\sqrt{t} + bt$$

Here the constants a and b are related to the parameters of the problem. This analysis has been completed for a spherical and a parallelepiped-shaped canister.

The surface regression speed in this model can either be taken from the exterior-field mass transfer calculations given in the section on mass transfer into the exterior liquid or from experimental data.

Radionuclide Transport Through Fractured Rock

Previously, the analysis for the transport of a single radionuclide species through macrofissures bounded by walls with micropores was described. The analysis has been extended to the transport of a decay chain of arbitrary length. An exact recursive solution has been obtained. Explicit solutions for space-time-dependent concentrations of daughters in the decay chain are possible by neglecting radioactive decay in the micropores.

Concentration profiles for the radionuclide chain $^{234}U \rightarrow ^{230}Th \rightarrow ^{226}Ra \rightarrow$ are shown as the solid lines in Figure 1. Also shown are the profiles calculated for porous flow transport. Because of the assumed lack of sorption on the macrofissure surfaces, the front of the concentration profile in fracture flow moves at the water velocity. Time delays for diffusion into and out of sorbing micropores spread the concentration profile for fracture flow and considerably attenuate the peak concentrations below those predicted for flow through a porous medium with local sorptive equilibrium. For the parameters assumed here, the peak concentration of ^{226}Ra is a hundredfold less for fracture flow. An even greater reduction will occur if radioactive decay while in the micropores and sorption on the fissure walls are taken into account. The spreading of the concentration profile due to micropore diffusion is qualitatively similar to, but considerably greater than, spreading by dispersion.

FUTURE ACTIVITIES

Work will continue on the modeling of dissolution kinetics under expected repository conditions and as affected by backfill, application of the analytical solutions for radionuclide migration in two-dimensional flow fields, and effect of solubility limits and realistic dissolution kinetics on radionuclide migration.

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Harada, M., P. L. Chambré, K. Higashi, F. Iwamoto, D. Leung, T. H. Pigford, and D. Ting, 1980. Migration of Radionuclides through Sorbing Media: Analytical Solutions--I, LBL-10500, Lawrence Berkeley Laboratory, Berkeley, CA, February.

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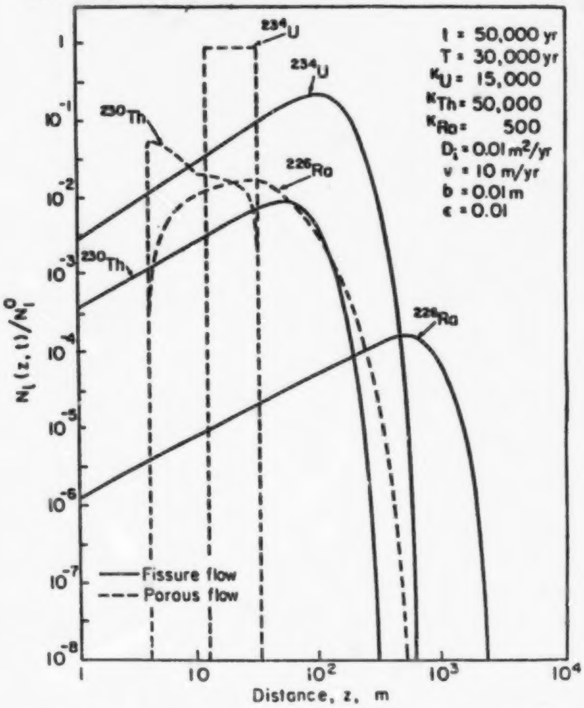

Figure 1. Concentration Profiles for Fissure Flow and Porous Flow at 50,000 yr. (T = leach time, K = retardation constant, b = fissure width).

WBS 1.1.5

PROJECT: Modeling of Waste Form Leaching

PRINCIPAL INVESTIGATOR: University of Illinois (A. J. Machiels)

ONWI PROJECT MANAGER: G. E. Raines

OBJECTIVE

The objective of this work is to develop and verify a model to calculate the probable leach rates of nuclear waste forms by aqueous solutions. The model integrates available experimental data into a mathematical formulation representing the fundamental physicochemical processes involved in waste form leaching. This approach is taken because long-term leaching behaviors must be extrapolated from experiments conducted for periods of time which are short relative to the time of interest.

PROGRESS REPORTED PREVIOUSLY

The project was started on January 6, 1981. Two key technical results were obtained for situations where network dissolution was negligible and leachant flow rates were large:

1. For simple glasses, the leach rate follows a $t^{-1/2}$ dependence, when interface phenomena are fast, whatever the concentration dependence of the diffusion coefficient might be; the existence of a one-parameter Lie group substantiates the argument mathematically.
2. For a constant diffusion coefficient, analytical solutions were obtained by using a Laplace transform technique.

Those two conclusions are significant, especially when short-term leaching behaviors are considered. Waste form-leachant interface phenomena can then be predominant, and departures from diffusion-controlled behaviors should be expected.

ACTIVITIES DURING THE REPORTING PERIOD

When the events and processes which could lead to a failure of geologic containment are reviewed, it is generally concluded that the most probable failure mechanisms would result in ingress of circulating ground water into the repository, leading to leaching of the waste and migration of radionuclides with ground water. The understanding of leaching behavior of waste forms is therefore required in order to evaluate waste package concepts.

The present understanding of leaching processes requires that models be kept as simple as possible. The number of parameters used should be kept to a minimum in order to emphasize the mechanisms which control leaching. A generic leach model was previously proposed, based on the applicability of:

1. Fick's law to describe the time and space-dependent concentrations of radionuclides in the solid waste form as they diffuse to the outer surfaces contacted by the water; and
2. Chemical kinetics rate equations to describe the exchange processes occurring at the leachant-solid waste form interface between species absorbed on the waste form and in solution.

The model assumes that the release of any given species from the solid waste form to the leachant solution proceeds by a series of steps, the last one being a surface process.

Since analytical solutions lend themselves to a better understanding of the effect of varying the model-relevant physicochemical parameters, they are relied upon whenever possible. Therefore, the Laplace transform technique has been used to develop analytical solutions for the aforementioned model when the rate-controlling mechanisms can be described in terms of parameters which do not change as a function of time.

Valuable physical insight can be gained by determining how leach rates vary at short and long terms. A possible approach is to obtain mathematical solutions valid at any time and determine the short and long-term trends from the analytical expressions obtained. However, the task may prove quite difficult and time-consuming. One can circumvent this difficulty by resorting to so-called Abelian and Tauberian theorems, i.e., by determining the asymptotic behavior of an image function when that of the original function is known. In order to take advantage of the Abelian theorems, one assumes that the leach rate, L(t), admits asymptotic representations of the form:

$$L(t) \simeq A_1 t^{\nu_1 - 1} + A_2 t^{\nu_2 - 1} + A_3 t^{\nu_3 - 1} + \ldots$$

as t becomes small with $0 < \nu_1 < \nu_2 < \ldots$

$$L(t) \simeq B_1 + B_2 t^{\nu - 1}$$

as t becomes large, with $0 < \nu < 1$,

where t is the time. That is to say that L(t) increases or decreases algebraically with time. This hypothesis appears to be amply justified in this case. Using this method, the coefficients A_1, B_1, and ν have been obtained from the Laplace transform expression of L(t).

Therefore, a key technical result during this quarter has been the development of a method which yields physical insight into leach rate trends while minimizing the required mathematical effort. A necessary condition, at this time, is the time-invariance of the parameters used to represent the mechanisms controlling waste form leaching.

FUTURE ACTIVITIES

During the coming quarter, a substantial effort will be devoted to the preparation of two reports: the first one will present a review of the important mechanisms controlling waste form leaching and describe the mathematical methods which have been used to compute diffusion-controlled leach rates; the second report will be devoted to the influences of interfacial processes occurring between the leachant and the waste form outer surface.

WBS 1.1.5

PROJECT: Sensitivity Analysis of Nuclide Retardation

PRINCIPAL INVESTIGATOR: Pacific Northwest Laboratory (M. O. Cloninger)

ONWI PROJECT MANAGER: H. C. Burkholder

OBJECTIVE

The objectives of this study are to (1) complete the documentation of a sensitivity analysis on the effectiveness of engineered barriers for spent fuel disposal in two reference geologic media, and (2) establish the sensitivity of those results and prior results for a reference salt site to variation in the net nuclide retardation capacity of the reference media. The results of the study will be useful in determining maximum sensitivity for far-field ground-water transport results to variation in, or uncertainty regarding, the net nuclide sorption capacity of a repository site.

PROGRESS REPORTED PREVIOUSLY

Work on this project was started in May 1981; this is the first report.

ACTIVITIES DURING THE REPORTING PERIOD

The systems performance code, consisting of the GETOUT, CONVERT, PABLM, and ALLDOS models, was reloaded from tape. After modification and several trial runs, the code is fully debugged and has enhanced efficiency for changing nuclide sorption data files for the parametric analysis.

The systems code is still deficient for very slow ground-water velocity (low Peclet number), and current plans are to include corrected equations in the GETOUT model.

FUTURE ACTIVITIES

The systems model will be applied to complete the transport calculations for an engineered barrier's performance versus dose consequences in reference repositories in granite and basalt. The nuclide sorption sensitivity calculations for the reference salt repository will be initiated.

SUMMARY

1.2 WASTE PACKAGE

The scope of the Waste Package Task covers waste form investigations and definitions, engineered barrier materials identification, the design and development of waste packages, and the performance assessment of the waste package. The prime objective of this task is to design and develop waste packages that enhance the performance of the total nuclear waste isolation system.

In the performance measures development project, work continued on sorting out the characteristics appropriate to waste package evaluation for the performance functions of containment, isolation, and handling. These hierarchical structures take into account various considerations that should affect decisions about preliminary and final waste package designs. In addition to this development of hierarchical structures, an interaction/cross-reference matrix was developed in order to represent the May draft of the 10 CFR 60 (U.S. NRC, 1980) technical criteria to the NWTS functional criteria for waste packages.

The spent fuel characterization task was reoriented when it became apparent that the existing data base on spent LWR fuel is insufficient to correlate postirradiation characteristics with reactor operating conditions and fuel manufacturing variables. An alternative approach using nondestructive (NDE) techniques was proposed. The techniques of interest are those which provide basic information on fuel rod conditions relevant to assessing possible dissolution and leaching behavior of spent fuel in a repository. NDE techniques currently available for application have been identified, and information and data were obtained by contacting LWR fuel performance program sponsors, fuel rod vendors, and supporting technical laboratories.

A surface area modeling subtask was begun during the quarter with the objective of providing a computerized model to define and characterize the effective surface area of spent fuel. The model is also intended to be applicable to ground-water leaching investigations. Development is proceeding using principles of quantitative stereology to define porosity effects. Segments of the model will separately consider intragranular and intergranular porosity, both on the fuel pellet surface and along internal cracks.

A study on spent fuel disassembly alternatives is under way to assess the impacts of five spent fuel alternative waste forms for geologic disposal and to recommend the reference form. During the reporting period assessments were made on technical, operating, safety, and economic bases. The results of these assessments, when utilized with the figure-of-merit methodology developed at the initiation of the studies, resulted in option 3 (disassembly and close packing being selected as the reference disposal waste form). Work was initiated in preparing an integrated recommendation report combining the results of three separate studies.

A technical report was drafted on the isolation of radioisotopes in geologic storage. The report describes the experiments on the Ca_2SiO_4-$CaNaPO_4$ binary system, hydration, and sorption.

The major activities for the development of backfill materials during this reporting period have been characterization of candidate backfill materials, radionuclide sorption (Kd) measurements on candidate backfill materials, measurement of backfill compaction properties, determination of hydraulic conductivities and swelling pressures of bentonite and bentonite-sand mixtures, and initiation of experiments designed to clarify the kinetics of backfill saturation.

PNL has begun preparing the starting materials for the selected phase compatibility experiments and has continued examinations of the results of various experimental runs. In addition, tests were run to determine the permeability of shale.

A draft field test plan has been prepared for implementing a backfill materials test in a salt mine in southeastern New Mexico. The backfill materials selected for these field tests consist of 100 percent bentonite and a mixture of 30 weight percent bentonite, 70 to 20 weight percent coconut charcoal, and 0 to 50 weight percent other. An assessment has been conducted on the production and availability of bentonite needed for a large-scale waste emplacement and mine tunnel backfilling program.

Sandia continued examinations of the surface structure of oxide in order to help elucidate the mechanisms of corrosion. General corrosion testing of several cast irons (primarily nodular) and 1018 steel in Brine A is in progress.

The time-temperature transformation characteristics study of TiCode-12 and Ti-50A is progressing. A series of boiling hydrochloric corrosion tests was performed on TiCode-12 samples in mildly annealed and "sensitized" conditions. A feasibility study has been started to assess the crushing (due to lithostatic pressure) behavior of thin TiCode-12 overpacks surrounding a steel HLW canister. Diffusion experiments, initiated last quarter in order to make direct migration measurements of Cs^+ and Sr^{++} in columns of wetted backfill materials, have been concluded. Similar experiments with Eu^{+++} and TcO_4^- are in progress.

During this period the steel sleeve from Site B of the Avery Island Salt Mine, with corrosion specimens attached, was removed from the mine and delivered to ORNL for examination. The sleeve, which was 5.5 m (18 ft) long with an inside diameter of 0.3 m (12 in), has been in the mine for three years.

The spent fuel stabilizer prebreach disposal condition test was completed. The objective of this test was to evaluate cladding-stabilizer material interactions under expected disposal cycle conditions prior to breach of the waste canister. Information on the moisture release and gas generation behavior of the candidate stabilizer materials was also developed.

Phase stability studies in waste form and material studies continue to focus on the structural integrity of ceramic waste forms. Several ceramic samples of cesium hollandite and potassium hollandite were produced; their densities of 80 to 90 percent of theoretical value are favorable for evaluating the transport of cesium ions in these types of structures. A microscopic formulation for conducting model studies of diffusion and leaching has been developed. The first research material, based on NBS glass K-1620 will be purchased, and developmental work on the second research material is continuing.

In material studies, initial results have been obtained using stainless steel 304 in a basalt ground-water environment. The bibliography on the corrosion of canister materials in underground environments is 75 percent complete. A review of possible canister degradation mechanisms and test methods is in progress. Fatigue crack growth rate tests are being used to evaluate the susceptibility of titanium grades 2 and 12 to stress corrosion cracking in a Hanford basaltic ground water.

Draft reports on engineered waste package conceptual designs for defense high-level waste and spent fuel (whole assemblies) for disposal in salt were received. These two reports were evaluated for compliance with the NWTS draft waste package system performance criteria. The conceptual design reports contained two basic design concepts: the borehole package design and the self-shielded package concept. An internal review committee did not find any major deficiencies that would result in the inability to successfully develop the reference conceptual design.

SAI has completed code and sensitivity studies to help review the planned matrix of variables for case studies for developing a waste package performance model. The package degradation and failure portion of the code has been revised to accommodate dual mode corrosion. The temperature subroutines have been revised to give a temperature profile in the package rather than the temperature of one barrier, and a detailed output option has been added, allowing a time map of events so that intermediate states can be examined.

Sensitivity studies were done to determine the sensitivity of the release model to many parameters and to do extensive checking. Some calculations in the degradation model were also done to determine if the original run matrix was appropriate.

At PNL, preparations continued for the shipment of the glass HLW log to NTS/EMAD. All of the cask-handling and shipping hardware has been fabricated and accepted. The cask-handling procedure is completed and approved. All training in reference to this program is complete. The PNL Operation Readiness Plan is complete and has been approved by the Operation Readiness Review Board.

Other Avery Island experimental studies involve heater stress gage data collection for borehole closure studies, thermal analysis of temperature data (final report in preparation), and radar scanning experiments for nondestructive investigation of salt conditions.

In the Avery Island salt mine experiment migration behavior was studied for two types of brine inclusions: (1) inclusions of in situ brine in KCl (100) single crystals at higher axial loads, and (2) mixed-brine inclusions (1M $SrCl_2$) in NaCl (100) single crystals and in natural rock salt. Experiments in (1) have been completed and the results analyzed. A preliminary model, based on the Burton-Cabrera-Frank theory of crystal growth, has now been carefully reconsidered and refined to account for the observed effects. Experiments in 2 are still in progress with the NaCl crystals, and experiments with natural rock salt have just started.

For gas-liquid inclusions, the objectives were to adapt the numerical analysis of the hemispherical gas bubble to the brine migration process and to develop numerical algorithms for computation. The original computer program for a hemispherical bubble in an infinite extent of liquid was modified to a hemispherical enclosure and to include concentration effects. The development of numerical algorithms for the spherical liquid inclusion with a centrally positioned spherical gas bubble is complete for the decoupled temperature effects.

WBS 1.2.1

PROJECT: Performance Measures Development

PRINCIPAL INVESTIGATOR: Arthur D. Little, Inc. (C. R. Hadlock)

ONWI PROJECT MANAGER: J. D. Waddell

OBJECTIVE

The objectives of this program are (1) to provide a complete set of performance measures in six categories (environmental impact, societal impact, safeguards, safety, economics, and resource consumption) for use in analyzing NWTS program options, (2) to provide assistance to ONWI in implementing the measures in the NWTS System Evaluation Model, and (3) to develop a set of performance measures specific to waste package evaluation.

PROGRESS REPORTED PREVIOUSLY

This project began on 21 May, 1980. Principal activities reported previously include these:

- A detailed set of performance measures was developed to categorize each of the six categories listed above. These performance measures represented a quantitative set of characteristics that could be used to measure all relevant aspects of the six categories.
- In order to facilitate the application of the performance measures to a variety of NWTS decisions, logical subdivision charts were developed for each of the six performance categories.
- NWTS criteria documents were reviewed from the point of view of performance measures.
- Decision considerations were identified for the question of whether to build an Intermediate Scale Facility.
- Waste package literature was reviewed to determine the availability of specific performance measures that would facilitate decisions concerning the waste package program.
- A program was outlined for the development of performance measures specific to the waste package.

ACTIVITIES DURING THE REPORTING PERIOD

Hierarchical structures intended to sort out the characteristics appropriate to waste package evaluation were constructed for the subject areas of containment, isolation, and handling. These structures take into account various considerations that should affect decisions about preliminary and final waste package designs. Examples of such considerations include technical conservatism; performance of individual barriers; performance of integrated waste package systems; overall reliability of performance of the full complement of waste packages; reference repository conditions; other hypothetical repository conditions for which waste package performance may need to be evaluated, such as early repository resaturation; the behavior and likelihood of substandard waste packages; and the various methods by which performance measures may need to be calculated, such as by laboratory or field tests, mathematical modeling, engineering judgments, etc.

In addition to this development of hierarchical structures, an interaction/cross-reference matrix was developed in order to represent the May draft of the 10 CFR 60 (U.S. NRC, 1980) technical criteria to the NWTS functional criteria for waste packages.

FUTURE ACTIVITIES

The following quarter will include three principal activities:

- The three hierarchies developed during the last quarter will be revised to incorporate ONWI comments and will be expanded to include

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the full range of handling considerations as well as retrievability. In addition further details on the nature of the interaction between 10 CFR 60 and NWTS criteria will be incorporated on the cross-reference matrix.

- The hierarchies will be used to define specific performance measures relevant to the NWTS final decision to fabricate and emplace production waste packages. This decision will be made several years in the future, and the identification of performance measures at this point in time will help to drive the data acquisition program to be sure that all relevant information is available for decision making.
- Work will begin on the final version of the August 1980 report on performance measures for the waste isolation system. These performance measures deal with the categories of safety, environmental impact, societal impact, resource consumption, economics, and safeguards.

REFERENCE

U.S. Nuclear Regulatory Commission, 1980. "Technical Criteria for Regulating Geologic Disposal of High-Level Radioactive Waste; Advance Notice of Proposed Rulemaking" (10 CFR 60), Federal Register (45 FR 31393), Washington, D.C., May 13.

WBS 1.2.2

PROJECT: Spent Fuel Studies

PRINCIPAL INVESTIGATOR: Hanford Engineering Development Laboratory (HEDL) (R. J. Cash)

ONWI PROJECT MANAGER: J. A. Carr

OBJECTIVE

The objective of this program is to identify, analyze, and quantify those characteristics of spent fuel which significantly affect leaching and dissolution and those processes which may be active to degrade such fuel characteristics during the period from emplacement in a geologic repository until breach of the waste package. This work focuses on the performance of the spent fuel waste form and its long-term resistance to release of radionuclides. Correlations to predict these properties as a function of time will be developed and evaluated based on theoretical considerations and available data.

This work and the correlations developed will ultimately be used to help establish appropriate repository and waste package design limits and aid in long-term performance assessments of spent fuel package designs and candidate repositories.

PROGRESS REPORTED PREVIOUSLY

This program started at the beginning of FY 81. Other HEDL work on spent fuel package performance began in FY 78. Recent accomplishments include the following.

Spent fuel characterization and degradation studies identified surface area, surface structure, grain boundary conditions, fission product positions, fuel phases, and valence states as important fuel characteristics that might significantly influence the dissolution and leaching rates of radionuclides. Chemical changes in the fuel, volatile fission product migration, diffusion of gas to grain boundaries, radiation damage due to decay of fission products, and fragmentation due to thermal or mechanical effects were identified as mechanisms which could possibly change spent fuel characteristics during repository residence. It was concluded that, in intact fuel, volatile fission product migration, fragmentation, and radiation damage would not take place to any extent that could damage the fuel. Gas diffusion would also have little or no effect on the fuel, but it might influence the canister design. Studies using 10-year-old fuel indicate that chemical changes should not be a problem either, but it is recommended that the change in valence state with decay of cesium and barium be investigated further.

ACTIVITIES DURING THE REPORTING PERIOD

Nondestructive Techniques for Spent Fuel Characterization

The spent fuel characterization task was reoriented when it became apparent that the existing data base on spent LWR fuel is insufficient to correlate postirradiation characteristics with reactor operating conditions and fuel manufacturing variables. An alternative approach using nondestructive (NDE) techniques was proposed, and work has begun. As part of the reorientation, HEDL completed an assessment of spent fuel characterization approaches and started a critical analysis of NDE techniques. The purpose of this work is to determine the potential application of various nondestructive and quasi-nondestructive fuel rod examination techniques for screening and classification of spent LWR fuel rods prior to geologic disposal. The techniques of interest are those which provide basic information on fuel rod conditions relevant to assessment of possible dissolution and leaching behavior of spent fuel in a repository.

Three major features of interest are (1) identification of breached fuel rods, (2) determination of relative fission product inventories and distributions, and (3) determination of relative macro- and microstructural conditions (e.g., fuel surface area potentially available to ground water). Particular emphasis has been placed on identifying and assessing NDE techniques available for the last two features listed above.

NDE techniques currently available for application have been identified, and information and data were obtained by contacting LWR fuel performance program sponsors, fuel rod vendors, and supporting technical laboratories. Evaluation indicates potential applications of at least one or more currently available NDE techniques to each of the three characterization areas listed above. Both poolside and hot cell applications are under consideration, with particular emphasis on the former because of assumed economic benefits.

It was recognized early in the study that fuel rod vendors typically treat their experience with most NDE techniques as proprietary information. Each vendor has developed specific techniques for conducting various poolside fuel rod examinations. Vendor identification of breached LWR fuel rods at poolside currently involves combinations of such NDE techniques as visual, sipping, eddy current, and ultrasonic examinations. Thus, a relatively extensive history of experience currently exists.

Various types of gamma scanning are clearly the best choice among available NDE techniques for characterizing fission product inventories and distributions, especially for poolside applications. Except for radiography (neutron or X-ray), currently available NDE techniques do not offer much "direct" evidence on the physical condition of irradiated LWR fuel. Radiography can easily provide general information on the extent of fuel cracking and large voids in the fuel column. Aside from cracks and pellet-pellet interfaces, other major void features of interest within the fuel are the extent, distribution, and microstructural location of fuel porosity. Relative to the nominal as-fabricated condition of fuel, it appears that the most promising NDE or quasi-NDE technique for detecting significant irradiation and thermally induced changes in porosity is via fission gas release. As an example, high LWR fission gas release (e.g., >10 percent) is indicative of a more interconnected and open intergranular fuel porosity condition. Two vendors are currently known to have poolside plenum puncture - fission gas sampling - resealing systems. An NDE technique currently under development, both in the U.S. and in Europe, for poolside fission gas release (plenum) measurements is gamma scanning for ^{85}Kr. Further investigations and assessment of NDE technique capabilities for this application are under way.

Surface Area Modeling

This subtask began in May 1981 with the objective of providing a computerized model to define and characterize the effective surface area of spent fuel. The model is also intended to be applicable to ground-water leaching investigations.

A preliminary mathematical representation of the surface area model was devised; it is being developed to provide both "time zero" and time-dependent characterization of the surface. Development is proceeding using principles of quantitative stereology to define porosity effects. Segments of the model will separately consider intragranular and intergranular porosity, both on the fuel pellet surface and along internal cracks.

Analytical Technique for Quantitative Characterization of Spent Fuel

This subtask began in May 1981 to determine the state of the art of various analytical techniques and instruments to quantitatively characterize spent fuel surface and grain boundary conditions and fission product residence positions.

A survey was started via letter to determine the existing state of the art and technology for the following determinations in spent LWR fuel: (1) identification of phases, (2) fission product residence positions, (3) identification of grain boundary conditions, and (4) fuel surface valence states. Letters were sent to numerous instrument manufacturers and to analytical laboratories throughout the U.S. Auger and electron spectroscopy for chemical analysis (ESCA) show potential for determining elemental analysis, residence position, and molecular composition in phases concentrated above bulk concentration values. Residence positions at concentrations under about 1000 ppm may require the use of secondary ion mass spectroscopy (SIMS) since Auger and ESCA are incapable of detecting concentrations lower than about 1000 ppm. The effect of radiation on these methods of analysis will be investigated next to determine if the sensitivity of the various methods will be seriously degraded when irradiated samples are examined. Present laboratory capabilities are also being assessed.

Effect of Limited Ground-Water Contact on Spent Fuel Characteristics

After ground water enters the waste package, the most likely mode of cladding breach is a pinhole. Water entering the fuel-cladding gap will be stagnant, will remain in contact with the fuel for a long period of time prior to additional cladding breaches, and will have a high fuel-to-water ratio. The purpose of this subtask is to review the literature to see if there is any evidence for this type of effect, to determine the condition of the water trapped in the fuel-cladding gap, and to analytically assess, if possible, the expected effects on the fuel and the rate of expected deterioration.

Very little past work is applicable to this task. In general, breached fuel rods in water storage pools are not ceramographically examined for fuel deterioration. Most effects observed in water-logged fuel when in pool storage can be attributed to the continuing release of fission products due to irradiation.

FUTURE ACTIVITIES

Evaluation of nondestructive techniques for characterizing spent fuel will continue, and the critical analysis phase will be completed. Surface area model development will continue with the definition and characterization of spent fuel surface area at "time zero". This development will be within the framework of a time-dependent surface model compatible with eventual linkage to a leaching model.

Evaluations of various analytical techniques to characterize spent fuel will continue and their sensitivity to radiation will be determined. Existing instrumentation and its capability within the U.S. will be categorized.

A description of the leachant after it has stagnated in the fuel-cladding gap (pH, composition, etc.) will continue. In addition, identification of possible effects of the leachant on the fuel condition and ways of analyzing these effects will be initiated.

WBS 1.2.2

PROJECT: Spent Fuel Disassembly Alternatives Impact

PRINCIPAL INVESTIGATOR: E. R. Johnson Associates, Inc. (E. R. Johnson)

ONWI PROJECT MANAGER: J. A. Carr

OBJECTIVE

The objective of this study is to obtain an assessment of the impacts of four spent fuel disassembly alternatives on the nuclear waste isolation system relative to the disposal of unmodified spent fuel. Such impacts will include consideration of relevant technical, operational, safety, and economic factors. The disassembly alternatives will include (1) end bell removal, (2) fission gas venting and resealing, (3) fuel disassembly and close packing of fuel pins, and (4) fuel chopping and immobilization.

An additional objective is to integrate the results of this study with the results of the evaluation of waste form performance by Westinghouse-HEDL and the development of waste package design criteria by Westinghouse Advanced Energy Systems Division (AESD), and to prepare an integrated, stand-alone report.

A recently added objective is to describe the performance requirements imposed on process equipment by the preferred process, disassembly and close packing of fuel pins, and to describe the capability of equipment currently available or under development to meet these objectives.

PROGRESS REPORTED PREVIOUSLY

A review was made of the design of the process and facilities for the packaging and disposal of unmodified spent fuel. This constituted the reference case for analyzing the impacts of spent fuel disassembly alternatives on the nuclear waste isolation system. Reference PWR and BWR fuel designs were identified, a review was made of the technology available for accomplishing the prospective disassembly alternatives, and the development of processes for each of these alternatives was undertaken. The additional facilities and materials necessary to accomplish each disassembly alternative (relative to the base case) were identified.

Packaging design parameters and costs were determined for each alternative. A methodology to compare the impacts of each alternative and the effects of human intrusion after repository closure was developed. Radiation exposures for plant workers were estimated, and a scenario for estimating possible exposures during a well-drilling intrusion into the repository was developed.

ACTIVITIES DURING THE REPORTING PERIOD

Technical and operating assessments for each of the four processes were made; Alternative Processes 2 and 3 rated slightly lower than the Reference and Alternative Process 1 on both of these assessments, and Alternative 4 rated significantly lower on both.

Safety assessments for the alternative processes were completed; the Reference Process and Alternative Processes 1, 2, and 3 proved to be essentially identical in safety risk, with Alternative 4 showing an enhanced risk from the more drastic processing required by that waste form. The differing impacts of the alternatives on the exposure to members of a drilling crew involved in an intrusion into the repository 100 years after closure were determined; little differentiation among the Reference and Alternative Processes was afforded by this evaluator.

Economic assessment of each alternative process was made in terms of incremental costs for facilities as compared to the Reference Process, plus estimated operating and packaging costs based on the number of emplacements required for each alternative. The total costs for each alternative over the life of the project were determined and reduced to a unit cost in dollars/kilogram of fuel emplaced. Costs for the Reference Process were modified from the Bechtel Conceptual Reference Repository Description estimate to take into account some minor differences between the process described in that document and the Reference Process used as the basis of comparison. Alternative Processes 1 and 2 were slightly better than the Reference Process, and Alternative Processes 3 and 4 were significantly better.

The four alternative processes were compared to the Reference Process in respect to each of the four assessment areas, employing the Figure of Merit methodology developed during this study. The Figure of Merit developed for each process reflected the results of the assessments made during the course of this study and a comparative analysis of the advantages and disadvantages of each disassembly alternative. Based on this, it was concluded that Alternative 3, involving the disassembly of spent fuel and packaging and disposal of the resulting fuel pins, is the preferred method of disposing of spent fuel.

Work was initiated on preparing an integrated report presenting the significant elements of the results of the studies by Johnson Associates, Westinghouse-HEDL, and Westinghouse AESD.

Work was initiated on developing design criteria for disassembly equipment and assessing the capabilities of equipment now in existence or under development to meet these criteria. Both the Allied General Nuclear Services fuel bundle disassembly dry process and the Nuclear Assurance Corporation underwater system were reviewed with the respective operators. Contacts have been made also with other organizations having experience in fuel bundle disassembly to obtain information on methods employed and problems encountered.

FUTURE ACTIVITIES

Work will continue on developing and reporting design criteria.

WBS 1.2.3

PROJECT: Desiccant Materials Screening

PRINCIPAL INVESTIGATOR: Lehigh University
(D. R. Simpson)

ONWI PROJECT MANAGER: D. P. Moak

OBJECTIVE

The objectives are to determine the phase relations in the Ca_2SiO_4-$CaNaPO_4$ system and to determine the suitability of selected compositions for backfill by hydration reactions.

PROGRESS REPORTED PREVIOUSLY

$CaNaPO_4$-Ca_2SiO_4 Binary

A literature review of the binary system Ca_2SiO_4-$CaNaPO_4$ revealed major disagreement in the published phase diagrams, so experiments were designed for a systematic study of the phase relation. It was found that $CaNaPO_4$ stabilizes the high-temperature polymorphs of Ca_2SiO_4. The stabilized high-temperature phases were produced in sufficient quantity to serve as stock material for hydration and sorption studies.

There was a continuing effort on refining the anhydrous phase relations.

Hydration Studies

$CaNaPO_4)_{100}$, $CaNaPO_4)_{50}Ca_2SiO_4)_{50}$, $CaNaPO_4)_{20}$-$Ca_2SiO_4)_{80}$, and $Ca_2SiO_4)_{100}$ were selected for the synthesis of bulk material for hydration studies. Four different solutions, containing 0.01 M of NaI, CsCl, $SrCl_2$, and $NaReO_4$, respectively, were used with each of the four powders. The filtrates obtained daily were analyzed for calcium, sodium, iodine, cesium, chlorine, strontium, rhenium, and pH.

Neither $CaNaPO_4$ nor $CaNaPO_4)_{50}Ca_2SiO_4)_{50}$ became impermeable by reaction with the solutions. $CaNaPO_4$ and $CaNaPO_4)_{10}Ca_2SiO_4)_{90}$ underwent incongruent solution, with sodium being leached from the bed. Interestingly, $CaNaPO_4)_{50}Ca_2SiO_4)_{50}$ did not show the selective leaching of sodium. This may reflect a difference in solubility of the compounds, with the intermediate compound being the least soluble and the least reactive. The leaching of sodium from the bed is desirable because the leached bed is then enriched in calcium and phosphate, which crystallize to the desired compounds apatite. Consistent with this finding is a decreased release of calcium from the bed with increased phosphate in the starting material.

The solution data indicate that some cesium is sorbed, especially in the beds enriched in Ca_2SiO_4. Some solution contained rhenium, added as $NaReO_4$, as a proxy for technetium. There was extensive sorption or reaction of rhenium with all filter beds. The sorptive capacity was first exceeded for the $CaNaPO_4$ bed.

Reaction of $CaNaPO_4$ under hydrothermal conditions (150 and 300 C), with solutions containing strontium, cesium, and iodine, yielded apatite. This mineral showed a small difference in lattice parameters if synthesized in a solution containing strontium or iodine compared to solutions lacking these ions, indicating some substitution of the ions in the crystals and not simply surface sorption. Cesium had no effect and therefore has insignificant substitution in apatite. All of these ions may be surface sorbed; however, the experiments were designed to determine only if there is structural substitution in the crystals.

Hydration of variants of Ca_2SiO_4 at 150 C resulted in the mineral hillebrandite [$Ca_2SiO_3(OH)_2$]. At 100 C for a period of one month, microscopic examination showed extensive hydration, but the product appeared amorphous to X-ray.

ACTIVITIES DURING THE REPORTING PERIOD

A technical report was drafted on the isolation of radioisotopes in geologic storage. The report describes the experiments on the Ca_2SiO_4-$CaNaPO_4$ binary system, hydration, and sorption. Major findings, as listed in the summary and conclusions, are as follows.

Pure Ca_2SiO_4 synthesized at high temperatures is either α or α' polymorph, but these polymorphs will invert during cooling to a γ form, which has a negligible rate of hydration. However, the solid solution of $CaNaPO_4$ in Ca_2SiO_4 increases the stability of the high-temperature polymorphs so that they can be readily synthesized and preserved for an extended period. These chemical variants of Ca_2SiO_4 lack true thermodynamic stability at low temperature, as shown by the binary relations between $CaNaPO_4$ and Ca_2SiO_4. However, during long-term exsolution experiments and hydration experiments, no evidence of any inversion to the low-temperature, nonhydraulic form, γ, was found. The minimum $CaNaPO_4$ necessary for the preservation of the high-temperature forms of Ca_2SiO_4 is about 4 mole percent.

The $CaNaPO_4$ variants of Ca_2SiO_4 are dense, equant crystals which as a powder have a bulk density of about 1.6 and roughly 52 percent porosity. In the presence of water, these powders hydrate to a hydrous calcium silicate and apatite. These products are poorly crystallized, and the particular calcium silicate which crystallizes is a function of the initial composition of the variant of Ca_2SiO_4 and especially the temperature of hydration. With hydration in the presence of excess water, sodium (and to a less extent phosphorus) is leached from the crystals.

Thermogravimetric analysis (TGA) and differential thermal analysis (DTA) show increased rate of hydration at room temperature with increased $CaNaPO_4$ solid solution up to 20 mole percent; however, the cementitious nature of the hydrated material decreases with increased $CaNaPO_4$ solid solution in the Ca_2SiO_4 host. Most of the water of hydration is expelled with heating to 150 C. The total water content after about a month of exposure of the anhydrous variants to water at room temperature ranged from 3 to 8 percent. Thus these materials have a relatively slow rate of hydration.

At elevated temperatures, the rate and extent of hydration increased and the products had superior cementing properties compared to hydrates formed at room temperature.

The variants of Ca_2SiO_4 richest in calcium showed sorption of strontium and rhenium from an infiltrating solution, but cesium and iodine show no retention.

MgO was subjected to the same conditions of hydration for comparison. Granular MgO of the same grain size as the variants of Ca_2SiO_4 has a comparable rate of hydration. TGA shows approximately half of the water lost below 150 C and approximately half at 400 C. These two water losses probably correspond to sorbed water and water of crystallization of brucite, $Mg(OH)_2$. By reducing the grain size of the MgO from -250 μ +125 μ to -65 μ, the rate of hydration to form brucite was increased nearly tenfold. It is likely that a similar increase in the hydration rate of the variants of Ca_2SiO_4 could be realized by a reduction in grain size.

An infiltrating solution loses some iodine, rhenium, and strontium in the course of hydrating and passing through an MgO filter. Whether these ions are loosely bound to the $Mg(OH)_2$, or salts with the ions entrained, is unknown.

Both the variants of Ca_2SiO_4 and MgO are desiccant materials. In a granular form, both have a high density and comparable rates of hydration. The extent of hydration is superior for MgO, and once hydrated it holds the water to over 300 C. Hydration results in a large volume increase with the product having a large surface area. This would lead to impermeability of the backfill, but the hydrate lacks cementitious properties. In contrast, the variants of Ca_2SiO_4 hydrate with cementitious properties, especially if the hydration is at elevated temperatures. However, these variants lack the high water capacity and thermal stability of the hydrated MgO. The two basic desiccant materials have different properties and reactivities. The most suitable one will depend on the environment in which it is emplaced and the conditions to which it is subjected.

In the course of this study, rhenium was used as a proxy for technetium because of the known similarity in properties. Rhenium was found to be retained in some of the filter beds. The manner in which rhenium is held, its valance, and its similarity in these conditions to technetium should be investigated.

WBS 1.2.3

PROJECT: Development of Backfill Materials

PRINCIPAL INVESTIGATOR: Pacific Northwest Laboratory (E. J. Wheelwright)

ONWI PROJECT MANAGER: D. P. Moak

OBJECTIVES

The objectives of this project are to define the optimum attributes of backfill materials and to develop the single-component or multicomponent backfill material that most nearly satisfies the prescribed attributes.

PROGRESS REPORTED PREVIOUSLY

This project began in March 1980. A prioritized list of backfill attributes was determined and a preliminary list of candidate backfill materials was chosen. A laboratory program to determine the properties of the candidate backfill materials was started and includes measurement of compaction properties, permeability, swelling pressure, sorption, and thermal conductivity.

ACTIVITIES DURING THE REPORTING PERIOD

The major activities during this reporting period have been (1) characterization of candidate backfill materials, (2) radionuclide sorption (Kd) measurements on candidate backfill materials, (3) measurement of backfill compaction properties, (4) determination of hydraulic conductivities and swelling pressures of bentonite and bentonite-sand mixtures, and (5) initiation of experiments designed to clarify the kinetics of backfill saturation.

Initial characterization of backfill materials has included X-ray diffraction (XRD) analysis, differential thermal analysis (DTA), and chemical analysis. Preliminary XRD analysis of five candidate backfill clays has been completed. Untreated sodium bentonite (CS-50), treated sodium bentonite (Accuofloc-350), and untreated calcium bentonite are normal montmorillonites as expected. One treated sodium bentonite (Saline Seal) is a mixed-layer clay containing a significant proportion of nonexpanding (illite) layers within its crystal lattice. Greensand is a polymorph of the mineral glauconite. The principal impurities in the bentonites are feldspar and quartz. DTA scans of untreated sodium and calcium bentonite have been completed. DTA scans carried out at the standard heating rate of 10 C/min are in general agreement with published data for bentonites and indicate major water loss at approximately 115 C for sodium bentonite and 130 C for calcium bentonite. DTA scans carried out at lower heating rates indicate that kinetic effects can strongly affect DTA results. Scans carried out at 0.1 C/min, the lowest rate possible on the available equipment, indicate a shift of the major water loss endotherms to 70 C for sodium bentonite and 75 C for calcium bentonite. At the lower heating rate, loss of loosely bound water from the sodium bentonite is essentially complete at 100 C. These results indicate that published standard DTA curves cannot be used to accurately predict the water loss behavior of various clay minerals.

The compaction density of naturally occurring calcium bentonite was determined as a function of compaction pressure (55 to 221 MPa) and water content (0 to 28 weight percent H_2O). Compared to previous results for sodium bentonite (CS-50), the compaction densities were lower at the same compaction pressure, but for the higher compaction pressures, the results showed a similar dependence on water content with a density maximum at approximately 8 weight percent water. Densities of 1.8, 2.01, 2.10, and 2.14 g/cm^3 were obtained for 2.96 cm diameter pellets at 8 weight percent H_2O content using compaction pressures of 55, 110, 166, and 221 MPa, respectively.

Batch distribution coefficients (Kds) for ^{125}I, ^{85}Sr, and ^{137}Cs with candidate backfill materials in synthetic Grande Ronde ground water have been measured for contact times of 14 and 28 days. The results indicate that strontium and cesium are retained by the clays and zeolites with Kds in the range of 10^3 to 10^4. Iodine was retained by pyrite, FeS_2, but the change of pH from 9.8 to 2.8 during the 28 day-tests indicate that pyrite is probably not a desirable backfill component. Iodine Kd values were also obtained for other suggested backfill additives. Iodine Kd values of 10^3 to 10^4 were obtained for silver-treated silica and mordenite; silver, cadmium, and lead-treated faujasite; and silver nitrate-treated bentonite clay; however, the stability of these materials in the backfill environment is uncertain. Technetium Kd values of approximately 7×10^3 were obtained using iron metal and charcoal. No other materials have been identified for technetium removal from ground waters.

Hydraulic conductivities and swelling pressures have been measured for sodium bentonite, calcium bentonite, and sodium bentonite-sand mixtures. Typical test results are listed in Table 1. Although the hydraulic conductivity of the calcium bentonite is higher than that of the sodium bentonite, and the swelling pressure is somewhat lower, the calcium bentonite may be acceptable as a backfill material.

Values for hydraulic conductivity can be used to evaluate the rates at which water will move through a backfill once it is saturated. They, however, provide little information about the time required for water to move through the backfill initially. A series of experiments has been initiated, using the existing permeameters, to help quantify this important parameter. Sodium bentonite (CS-50) was pressed at 138 MPa into 5 cm diameter cells to form cylinders of clay 0.5, 1.0, and 2.0 cm thick and with a density of 2.1 g/cm^3. Grande Ronde ground water was then forced through the clay compacts by a hydraulic head of approximately 15 MPa. The initial results are shown in Table 2.

The initial results are consistent with a model in which the hydration rate is controlled by the rate at which water can be forced through the portions of clay that have already saturated. Movement of water through 0.5 cm of clay required 4.6 days. If it is assumed that the first 0.5 cm of the 1 cm samples required 4.6 days, then the second 0.5 cm of the 1 cm sample required 13.8 days for water penetration.

FUTURE ACTIVITIES

Work during the next quarter will concentrate on measuring sorption Kds, hydraulic conductivities, and saturation times. In FY 82, work will be expanded to include material stability and compatability and diffusion studies.

Table 1. Typical Permeability Tests Results.

Backfill Material	Density, g/cm^3	Head, MPa	Hydraulic Gradient	Time, hr	Hydraulic Conductivity, cm/s	Swelling Pressure, MPa
Sodium Bentonite	2.13	14.6	1.56×10^5	766	5.6×10^{-13}	58
Calcium Bentonite	2.11	15.4	1.59×10^5	617	1.6×10^{-12}	31
50% Sodium Bentonite 50% Sand (80-120 mesh)	2.09	16.7	1.73×10^5	618	6.4×10^{-12}	22

Table 2. Results of Preliminary Saturation Tests.

Clay Thickness, cm	Hydraulic Head, MPa	Time to H_2O Breakthrough, days
0.5	15.2	4.6
1.0	14.5	18.9
2.0	15.2	0(a)
0.5	3.4	0(b)

(a) No breakthrough in 30 days, estimated days to breakthrough = 80 to 120.

(b) No breakthrough in 22 days.

WBS 1.2.3

PROJECT: The Chemistry and Physics of Nuclear Waste-Rock Interactions

PRINCIPAL INVESTIGATOR: Pennsylvania State University (W. B. White)

ONWI PROJECT MANAGER: J. B. Moody

TASK 1: NUCLEAR WASTE ARGILLACEOUS ROCK INTERACTIONS

OBJECTIVE

The objectives are (1) to repeat certain key waste-rock interaction experiments using more reactive younger shales and determine if there is a change in the expected reaction chemistry; (2) to continue the canister-waste-rock interactions and the sequence of experiments on the transport mechanisms of radionuclides in massive shales to determine the distribution of elements along the diffusion gradient and the partitioning of elements among the mineral phases to provide a basis for deducing the transport mechanisms in the actual repository environment; (3) to synthesize the rare earth reaction product phases and determine their X-ray powder diffraction patterns, chemical composition, and the relationship of the various structures as a function of a rare earth ion.

PROGRESS REPORTED PREVIOUSLY

Progress on the work begun 1 October, 1977 relates to identification of chemical reactions and transport mechanisms for reactions of prototype nuclear wastes with argillaceous rocks under specified temperature, pressure, and fluid composition conditions. Initially, the experiments dealt with the stability of the waste forms under hydrothermal conditions, especially in the presence of bittern brines. The glass-brine, ceramic-brine, and spent fuel-brine interactions experiments are completed, and the results will be published.

The second sequence of experiments dealt with binary interactions among simulated waste forms with generic shale rocks in the presence of specified fluids. Some 30 compounds have been identified as the reaction products of the wastes with the aluminosilicate and other minerals found in the shales. Reaction runs of varying times determined the rate at which steady state is attained and whether the initial reaction product assemblages are modified after longer reaction times.

The third sequence of experiments included the canister as an interaction component, and the fourth is incorporating transport processes as well as bulk chemistry. The behaviors of specific radionuclides and their reaction products have been investigated. Cesium has been studied extensively, including its interactions directly with the various shales and their component clay minerals taken separately, as well as the stability of the principal cesium reaction product phase, pollucite, in the presence of various fluids. In a similar manner, the stability relations of the alkali uranyl silicates, which often appear as reaction product phases, were determined, and compatibility triangles for the system K_2O-UO_3-SiO_2-H_2O at 200 and 300 C were constructed.

ACTIVITIES DURING THE REPORTING PERIOD

Preparation of the starting materials for the selected phase compatibility experiments was begun. Examinations of the results of various experimental runs continued. These included runs attempting to synthesize and identify the unknown rare-earth silicate phases encountered in the main series of experiments: 6-month, 100 C interaction runs with glass and various shales; 6-month, 100 C interaction runs of SPC-2 tailored ceramics and various shales; and the long-duration runs. X-ray diffraction analyses of the solid reaction products and analyses of solutions from capsules of binary interaction runs of shales, clays, or zeolites treated with strontium, lanthanum, and neodymium (lanthanum and neodymium simulate americium and curium because no stable isotopes exist) at 200 C/300 bars for 12 weeks have been completed. Results of the solution analyses appear in Table 1. The results indicate that Sr added as $SrCl_2$ reacted strongly only with Salona shale by forming strontianite. However, $SrCl_2$ also reacted with montmorillonite, clinoptilolite, and mordenite, probably by ion exchange and/or by forming new Sr minerals. When $Sr(OH)_2$ was added, Sr reacted with all the shales, clay minerals, and zeolites by forming new minerals such as $SrAl_2Si_2O_8$, $Sr_2MgSi_2O_7$, $SrCO_3$, and Sr-wairakite. The elements La and Nd reacted probably by forming La_2O_3 or Nd_2O_3 with all the samples except kaolinite. The carbonate-rich Salona shale reacted almost completely with the added La or Nd by forming $LaCO_3OH$ or $NdCO_3OH$ (Table 1).

The results of the Sr, La, and Nd interactions with shales, clay minerals, and zeolites suggest properly designed backfills will be very effective in immobilizing Sr and probably Am and Cm if they are released during the thermal period.

The first attempt was made to run the ion migration studies in a high pressure-temperature vessel. Two shales with different chemistries were used: an organic-rich Antrim and an oxidized Brallier. The solution consisted of a mixture of uranium, gadolinium, neodymium, strontium, and cesium in soluble salt form. The initial experiment, run at 250 C for 28 days, failed. No solution remained when the Teflon-lined, aluminum digestive vessel was opened. The Brallier shale sample was examined by scanning electron microscope (SEM) and will be characterized by X-ray diffraction (XRD). A second run of Brallier shale was placed in two small Morey pressure vessels for 1 week at 200 C. In this case one vessel functioned properly. The solids which underwent a color change will be analyzed by SEM and XRD. The solutions will be analyzed for ion content.

In addition, tests were run to determine the permeability of shale. When the shale layers were parallel to the applied pressure, permeability was very small. However, when the layers were perpendicular to the applied pressure, the permeability increased. The deionized water which passed through the shale was analyzed. The largest concentration of ions was that of calcium with some magnesium and iron.

Table 1. Solution Analyses of Hydrothermal Interaction Runs[a] of Shales or Clays or Zeolites With Strontium, Lanthanum, and Neodymium.

Sample Name	Sr[b] Uptake From $SrCl_2$	Sr[b] Uptake From $Sr(OH)_2$	La[b] Uptake From $LaCl_3$	Nd[b] Uptake From $NdCl_3$
Antrim Shale	3.7	95.4	35.2	42.6
Brallier Shale	0	97.9	22.9	37.3
Conasauga Shale	0	98.4	33.3	45.9
Salona Shale	61.2	97.5	98.8	99.99
Chlorite	0	64.3	52.3	79.2
Fithian Illite	0	96.4	35.2	36.4
Kaolinite	47.3	96.4	5.7	3.6
Montmorillonite, AZ	25.6	97.8	60.0	62.6
Clinoptilolite, ID	44.4	98.2	65.2	72.7
Mordenite, AZ	26.2	96.9	45.8	42.5

(a) 200 C for 12 weeks under a confining pressure of 300 bars.
(b) 9.42 mg of strontium as $SrCl_2$, 9.995 mg of Sr as $Sr(OH)_2$, 9.725 mg of lanthanum as $LaCl_3$, and 9.68 mg of neodymium as $NdCl_3$ were added to 100 mg of each sample.

FUTURE ACTIVITIES

The long-duration and metal-containing experiments will be completed and reported. Capsules containing binary interaction runs of Sr, La, and Nd with clay minerals, shales, and zeolites that leached will be repeated. Analysis of these binary interactions will be finalized and reported. The report on the system $K_2O-UO_3-SiO_2-H_2O$ will be completed.

A time-temperature regime which best shows ion migration will be determined. Solutions containing U, Nd, Gd, Cs, and Si will be forced through the shales, simulating fluids moving out from a repository.

TASK 2: REPOSITORY BEHAVIOR DEDUCED FROM LITERATURE DATA

OBJECTIVE

The objective is to make a systematic survey of the relevant geologic literature, summarize this information in a way useful for repository design, and draw such conclusions as possible about the repository processes from the experimental data.

ACTIVITIES DURING THE REPORTING PERIOD

The literature review of low-grade metamorphic and diagenetic reactions in several common host rock types has been for the most part completed.

FUTURE ACTIVITIES

The final sections of the topical report (on anticipated repository behavior) dealing with alteration reactions in tuffaceous sediments, basalts, and granites, along with an annotated bibliography, will be written.

TASK 3: BRINE MIGRATION IN SALT

OBJECTIVE

The objectives are (1) to finalize the characterization of Avery Island salt to determine what new analytical procedures are necessary to differentiate between samples for the migration experiments and (2) to learn more about thermal gradient migration of brine inclusions in polycrystalline salt with the use of the brine migration cell and alternative tracer techniques.

PROGRESS REPORTED PREVIOUSLY

Methods of preparing hot-pressed samples of NaCl with carefully controlled microstructures were described previously. These synthetic materials were used in the migration experiments. The design and construction of two types of migration cells were described. Previous results using synthetic salt showed that large thermal gradients on the order of 50 C/cm produce migration rates of orders of magnitude greater than those predicted by theory. The migration path seemed to be relatively independent of salt microstructure. When smaller thermal gradients of 3 to 7 C/cm were used, the migration velocity in the synthetic salts was 10 times higher than the calculated values of 4 to 5 cm/year. From microstructural examination it was evident that the migration paths occurred principally along the grain boundaries.

ACTIVITIES DURING THE REPORTING PERIOD

The second series of migration runs using different salt grain sizes at maximum thermal gradient is complete except for replication runs. Samples are now being processed for microstructure and brine penetration anlayses.

A new tracing technique in which one weight percent of CaCl moisture indicator is hot-pressed into the salt sample is being tested. Indicator color change should show to what level brine has penetrated into the sample. These results will be compared with other penetration measurements.

More than half of the samples for the wet and dry porous salt strength tests have been prepared. Work is progressing on sawing and grinding bar samples for transverse rupture bond testing.

FUTURE ACTIVITIES

The remaining salt samples for wet and dry porous salt strength tests and transfer rupture bond tests will be prepared and the tests will begin.

WBS 1.2.3

PROJECT: High-Level Waste Interactions

PRINCIPAL INVESTIGATOR: Sandia National Laboratories (M. A. Molecke)

ONWI PROJECT MANAGER: D. P. Moak

OBJECTIVE

The two technical objectives are:

1. To quantify the corrosion and metallurgical behavior of candidate HLW canister or overpack materials under environmental conditions to be expected in a salt repository and overtest conditions thereof; to provide and verify predictive models or assessments of the long-term barrier effectiveness of HLW canisters and overpacks based on laboratory, hot-cell, field, and in situ experimental results.
2. To develop and test backfill barriers to retard ground-water intrusion toward the waste package and to significantly delay radionuclide migration (via "getter" additives). This backfill getter is to be compatible for HLW or TRU waste isolation in a salt repository.

PROGRESS REPORTED PREVIOUSLY

Sandia has been experimentally involved in the corrosion behavior of waste container materials since FY 76, and in studies for backfill-getter development since FY 77. Current studies since July 1980 have been conducted in a generic manner applicable to the isolation of wastes in a salt repository.

Several candidate canister-overpack alloys were selected after multiple screening tests and assessments for superior corrosion resistance in brines. The prime candidate overpack material selected, the titanium alloy TiCode-12, has received much additional testing in the areas of general and localized attack, stress corrosion cracking (no susceptibility found), hydrogen embrittlement (further analyses required), mechanisms of degradation, and physical and mechanical metallurgy.

Bentonite clay has been selected as the primary backfill material due to its chemical and physical properties in a brine environment. Initial screening studies on additional candidate getter materials (e.g., for fission products, anions, etc.) have been completed. Advanced studies on chemistry and materials testing, geoengineering, field testing, and effectiveness modeling are in progress.

ACTIVITIES DURING THE REPORTING PERIOD

Work continued on the examination of the surface structure of oxide in order to help elucidate the mechanisms of corrosion. Electrochemical polarization investigations, largely on binary titanium-molybdenum alloys, show good oxide passivity in nonoxidizing acids. Auger depth profiles of TiCode-12 corroded in pH = 1, 200 C brine, showed enhancement of nickel in the oxide layer. Work has begun on the examination of surface oxides using Raman spectroscopy in situ with concurrent electrochemistry.

General corrosion testing of several cast irons (primarily nodular) and 1018 steel in Brine A is in progress. This is in support of the Westinghouse conceptual waste package design. Corrosion tests are being conducted as a function of time (10 days to 6 months) and temperature (50, 70, 90, and 150 C).

The first phase of a program to optimize the chemistry and processing procedure of TiCode-12 in terms of mechanical and corrosion properties has been initiated. Six 70 kg ingots with slightly different compositions were double-melted and forged into 5 cm thick slabs. Two product forms, thin sheet and plate, will be investigated. The objective of this work is to be able to write material procurement specifications for TiCode-12.

The time-temperature transformation characteristics study of TiCode-12 and Ti-50A is progressing. General corrosion resistance as a function of annealing time, temperature, and resulting microstructure is being addressed. All aging experiments have been completed.

A series of boiling hydrochloric corrosion tests was performed on TiCode-12 samples in mildly annealed and "sensitized" conditions. Enhanced corrosion was observed in the sensitized specimen, but the degree of enhancement was not as large as previously observed elsewhere. This potential enhancement will be investigated in detail because of the impact it may have on weld-affected zones of an overpack.

A feasibility study has been started to assess the crushing (due to lithostatic pressure) behavior of thin TiCode-12 overpacks surrounding a steel HLW canister. This study is assessing the merits of (1) using a hydrostatic pressure chamber to simulate in situ lithostatic pressures, and (2) fabricating a reduced-scale steel canister and TiCode-12 overpack for testing in the hydrostatic chamber. Calculations are in progress. The gap between the canister and overpack will be 0.5 inches. TiCode-12 having a thickness of 1/16, 1/8, and 1/4 inch will be evaluated for both commercial and defense HLW packages.

Diffusion experiments, initiated last quarter in order to make direct migration measurements of Cs^+ and Sr^{++} in columns of wetted backfill materials, have been concluded. Similar experiments with Eu^{+++} and TcO_4^- are in progress. A complete evaluation of all results is still in progress. However, the Kd values for Cs^+ evaluated from the column measurements are greater than those determined from previous batch Kd measurements; agreement is within a factor of two. For Sr^{++}, results indicate higher than anticipated retention at the top of the bentonite column, possibly due to precipitation. Efforts are being made to model this behavior through additional experiments. Autoradiographs of the sectioned columns did not indicate any channeling of radionuclides through the column.

A draft field test plan has been prepared for implementing a backfill materials test in a salt mine in southeastern New Mexico. The thermomechanical and geochemical properties of two HLW backfills will be measured in conjunction with an electric heater as emplaced in a drilled hole in the salt (approximately 80 percent halite) about 1300 ft below the surface. This test is expected to be operational in September 1981. The test site was visited and judged adequate, and is now being prepared for test initiation.

The backfill materials selected for these field tests consist of 100 percent bentonite and a mixture of 30 weight percent bentonite, 70 to 20 weight percent coconut charcoal, and 0 to 50 weight percent other (possibly sand as an inert filler material).

An assessment has been conducted on the production and availability of bentonite needed for a large-scale waste emplacement and mine tunnel backfilling program. Current production of this clay is adequate. Detailed results will be published.

FUTURE ACTIVITIES

The initial measurements of hydrogen effects on TiCode-12 will be reported. A preliminary assessment of particle migration in backfills will be completed. Summary technical documents will be issued on both canister-overpack studies and backfills.

WBS 1.2.3

PROJECT: Nuclear Waste Multibarrier System Development

PRINCIPAL INVESTIGATOR: Oak Ridge National Laboratory (J. C. Griess)

ONWI PROJECT MANAGER: D. P. Moak

OBJECTIVE

The objective is to obtain the necessary corrosion data so that various multibarrier waste package emplacement concepts in domal salt can be evaluated.

PROGRESS REPORTED PREVIOUSLY

Work on this project was started during the quarter; this is the first report.

ACTIVITIES DURING THE REPORTING PERIOD

During this period the steel sleeve from Site B of the Avery Island Salt Mine, with corrosion specimens attached, was removed from the mine and delivered to ORNL for examination. The sleeve, which was 5.5 m (18 ft) long with an inside diameter of 0.3 m (12 in), had been in the mine for three years (April 1978 to April 1981). Except for the flat bottom which rested directly on salt, the sleeve was separated from the salt by an air gap. A 3 kW electric heater cast in aluminum was inside the sleeve. The aluminum extended from 2.85 m (9.36 ft) to 5.39 m (17.67 ft) below the mine floor. The temperature was measured at three vertical locations on the sleeve, and these are shown at various times after the start in Table 1. Although sleeve temperatures at shallower depths were not measured, it may be assumed that they were appreciably less than those in Table 1.

The sleeve as received was covered with loosely adherent red rust with no significant difference in appearance along its length. The steel test specimens looked the same as the sleeve. All of the other specimens (titanium, Zircaloy-2, 304L stainless steel, Hastelloy C-276, and E-Brite 26-1) were bright and shiny with only an occasional spot of rust contamination from the sleeve. All were firmly attached either to the curved vertical surface or the flat bottom with stainless steel screws which were removed without difficulty.

All specimens except the carbon steel ones were examined microscopically, washed using a bristle brush, dried, and weighed. Since the corrosion products on the steel specimens were thick and poorly adherent, the specimens were cleaned in Clarke's solution (Clarke, 1936) (20 gm Sb_2O_3 and 50 gm $SnCl_2$ in one liter 37 percent HCl) before examination and weighing. Table 2 shows the weight changes observed on all test specimens and their vertical location on the sleeve.

Only the carbon steel test specimens experienced significant weight loss. Although average corrosion rates are given in Table 2, these values have little significance because attack was not uniform. The carbon steel specimen that was on the bottom of the sleeve suffered the worst attack. All the other carbon steel specimens underwent a similar uneven attack but to a lesser degree. A cross section through the region of worst attack on the specimen from the bottom showed a maximum penetration of 250 μm. The part of the flat bottom of the sleeve that appeared to have the heaviest attack was also sectioned, and the maximum depth of penetration found was 300 μm. Based on the data presented in Table 2 and the thermal history given in Table 1, it appears that attack of carbon steel was independent of temperature. In addition, a short length of sleeve material remained above grade on the floor of the mine for the three-year period. Attack on this steel was similar to that on the vertical sleeve below grade.

All other specimens, regardless of location, showed essentially no attack with two minor exceptions. A few shallow pits were adjacent to the screw heads on the two E-Brite 26-1 specimens

Table 1. Temperatures of Sleeve at Site B During Avery Island Test.

Distance Below Mine Floor, m	Days of Heating					
	1	15	75	300	500	1000
	Temperature, C					
3.1	110	132	133	133	134	135
4.2	134	155	158	158	159	160
5.3	90	107	109	110	110	112

Table 2. The Corrosion of Test Specimens Attached to the Carbon Steel Sleeve At Site B in the Avery Island Salt Mine During a Three-Year Exposure.

Materials	Depth Below Grade, m	Weight Loss, mg/cm^2	Average Corrosion Rate, μm/yr
Carbon Steel	0.61	8.53	3.6
Titanium	1.22	0.02	0.01
E-Brite 26-1	1.22	0.04	0.02
Carbon Steel	1.52	5.42	2.3
Hastelloy C-276	1.52	0	0
Zircaloy-2	1.83	0.02	0.01
Carbon Steel	1.83	5.16	2.2
Carbon Steel	2.13	4.36	1.9
E-Brite 26-1	2.13	0.03	0.01
Carbon Steel	2.44	5.21	2.2
304L Stainless Steel	2.74	0.06	0.03
Carbon Steel	3.05	4.59	2.0
304L Stainless Steel	3.66	0.05	0.02
Carbon Steel	3.66	4.68	2.0
Titanium	3.96	0.01	<0.01
Carbon Steel	4.27	3.91	1.7
Hastelloy C-276	4.27	0	0
Zircaloy-2	4.57	0.01	0.01
Carbon Steel	4.57	6.42	2.7
Carbon Steel	4.88	8.55	3.7
Carbon Steel	5.18	3.97	1.7
Zircaloy-2	5.49(a)	0.02	0.01
304L Stainless Steel	5.49(a)	1.12	0.45
E-Brite 26-1	5.49(a)	0.01	<0.01
Carbon Steel	5.49(a)	43.23	18.5
Titanium	5.49(a)	0	0
Hastelloy C-276	5.49(a)	0.04	0.02

(a) On bottom resting on salt.

on the vertical pipe wall; the deepest pit was 25 µm. The E-Brite specimen on the bottom in contact with salt had no pits. A very slight amount of localized attack on the Type 304L stainless steel specimen in the area of contact with the flat base of the sleeve was also noted. A transverse section through this region showed a maximum penetration of 20 µm with the average being only about half that value. The attack on this specimen looked like crevice corrosion, but this seems unlikely in view of the relative nobility of stainless steel and the carbon steel to which it was electrically connected; one would expect the carbon steel to cathodically protect stainless steel.

FUTURE ACTIVITIES

The carbon steel sleeve from Site A is scheduled for removal from the Avery Island Salt Mine during July 1981. When the test specimens from the mine arrive at ORNL, they will be examined in the same manner as those from Site B.

REFERENCE

Clarke, S. M., 1936. Transactions of the Electrochemical Society, Vol. 69, pp. 131-142.

WBS 1.2.3

PROJECT: Container Barrier Development

PRINCIPAL INVESTIGATOR: Pacific Northwest Laboratory (R. E. Westerman)

ONWI PROJECT MANAGER: D. P. Moak

OBJECTIVE

The objective of this project is to develop materials for the structural engineered barrier components of high-level nuclear waste packages. Structural barriers include the canister, the overpack, and the hole sleeve. The barrier elements must contribute substantially to a barrier system that will hold radioisotope release rates to near-zero values for time periods of ~1000 years.

PROGRESS REPORTED PREVIOUSLY

A program directed toward developing licensable structural engineered barrier elements for long-lived nuclear waste packages has been ongoing since January 1979. The major effort has been directed toward determining the corrosive and mechanical behaviors of metallic materials in simulated Hanford basaltic ground waters at temperatures to 250 C. Some attention has been given to ceramic and polymeric materials, and both deionized water and brine have been used in some experiments as the corrosive media.

Corrosion screening of nickel, iron, titanium, copper, and zirconium-base alloys in 250 C has constituted a major part of the work. Cast irons and steels are currently receiving the most attention. Determination of the stress corrosion cracking susceptibility of titanium alloys in basaltic ground water has also been a major effort, using slow strain rate tests and cyclic loading tests. These studies are continuing.

A dynamic autoclave facility is being constructed which will permit the exposure of test specimens to the combined effects of high-temperature aqueous environments (to 250 C) and gamma radiation (^{60}Co; 3×10^{6}r/hr).

ACTIVITIES DURING THE REPORTING PERIOD

Fatigue crack growth rate tests are being used to evaluate the susceptibility of titanium grades 2 and 12 to stress corrosion cracking in a Hanford basaltic ground water. Susceptibility is indicated by a frequency-dependent crack growth rate or by a crack growth rate that is high relative to an inert environment.

Fatigue crack growth rate tests run on two orientations of each titanium alloy at 90 C in simulated Hanford ground water at 1 Hz frequency showed no acceleration of crack growth rate due to the ground water environment. The fluoride content of the ground water has then increased from the "normal" 37 ppm to 220 ppm to provide a more severe environment. Tests have now been run at 1 Hz and 0.1 Hz in this high-fluoride solution at 90 C. In addition, one orientation of grade 12 titanium was tested in high-purity deionized water. The data from these tests were analyzed by fitting the data to the equation

$$\frac{da}{dn} = c\Delta K^{m},$$

where $\frac{da}{dn}$ is the fatigue crack growth rate, ΔK = cyclic stress intensity, and c and m are regression coefficients from a power curve fit. This procedure allows c and m to be compared for each test.

No significant difference was found between crack growth rates obtained in the air environment, normal fluoride Hanford ground water environment, or the high-fluoride Hanford groundwater environment. Tests were then begun on grade 12 titanium, longitudinal orientation, at 0.01 Hz. After four data points were obtained, an interruption in the water supply occurred and the test had to be terminated. The initial data points lie above the data scatterband of the high-frequency tests, indicating that a higher crack growth rate occurred. However, the amount of data is insufficient to draw definite conclusions. Low-frequency tests in high-fluoride Hanford ground water will continue during the next reporting period.

Slow strain rate tests have been done on grades 2 and 12 titanium at displacement rates of 10^{-4}, 10^{-5}, 10^{-6}, and 10^{-7} in/s in Hanford ground water at 250 C. Grade 12 has been tested in two orientations, and grade 2 has been tested in one orientation. Both titanium alloys exhibit a large loss of ductility with decreasing displacement rate, indicating enviornmentally induced damage. Fracture surfaces from specimens of both orientations of grade 12 titanium were examined in a scanning electron microscope for evidence of stress corrosion cracking, either intergranular or transgranular. All of the surfaces are rough and dimpled, typical of the "normal" void coalescence fracture mode. One interesting feature was observed: the presence of spherical particles on some fracture surfaces. These particles were found predominantly on specimens that were tested at the low displacement rates.

A test matrix for the first 12 months of testing in the radiation corrosion facility has been constructed, and sample holders have been designed. Initial tests will include corrosion coupons; stressed corrosion specimens (U-bends); stressed, precracked specimens (wedge opening load); and mechanical degradation specimens (Charpy V-notch).

Safety reviews have been held on the irradiation corrosion test facility by PNL and HEDL.

FUTURE ACTIVITIES

The following activities are planned:

- Fatigue crack growth rate tests of titanium alloys at low cyclic frequencies will continue.
- Constant elongation rate tests (CERT) of titanium alloys will be performed in air environments, for the purpose of obtaining control data.
- Fractographic examination of the surfaces of broken CERT specimens will continue.
- A screening test of selected cast ferrous materials in Hanford basalt ground water at 150 C will be initiated.
- The irradiation corrosion test facility will be started up.

WBS 1.2.3

PROJECT: Stabilizer Materials Program

PRINCIPAL INVESTIGATOR: Hanford Engineering Development Laboratory (R. J. Cash)

ONWI PROJECT MANAGER: D. P. Moak

OBJECTIVE

The objective is to identify, test, select, and qualify stabilizer materials for use in designing spent fuel waste packages. Emphasis is placed on selecting stabilizer materials that exhibit mineral interactions with the other waste package components.

PROGRESS REPORTED PREVIOUSLY

The spent fuel stabilizer fill process screening test was completed in March 1981. This test measured the interaction of candidate metal stabilizers with LWR fuel cladding during stabilizer emplacement at elevated temperatures. The material interaction test unit used for the fill process test consisted of a cladding specimen positioned in the center of a 1018 carbon steel (CS) capsule. The cladding specimens were fabricated with either Zircaloy-4 or 304 stainless steel (SS) with welded end caps. Stainless steel cladding specimens (14 Zircaloy-4 and 14 of the 304) were placed in 28 carbon steel capsules. Individual melts of four zinc and three lead alloys were poured into the capsules containing the two types of cladding specimens (two capsules per cladding type per alloy).

All 28 test units were placed into an air furnace at 425 C (above the melting point for all alloys) and held for one-half hour. The furnace was allowed to cool over a 30-minute period to 300 C, where it remained for another 15 hours. At this point, the test units were taken from the furnace and allowed to cool in air. This thermal history simulated a time-temperature cycle that potentially could be experienced by fuel rods in contact with a molten stabilizer in an actual waste canister during the fill process. Half of the test units were sectioned for electron microprobe examination to characterize fill process interactions. Neutron radiographs were taken of each fill process test unit from the side and top to help characterize any shrinkage voids that might have occurred during the process.

Measurable penetration by the metallic stabilizers was observed in the 1018 CS only. The stabilizer interaction ranged from minimal for zinc alloy AG40A to about 0.001-inch penetration with the zinc, copper, titanium alloy, the calcium lead, and the AC41A zinc alloy. None of the stabilizers exhibited interactions with the two cladding materials. Neutron radiography results on each fill process test unit indicated relatively large (approximately 1/8-inch diameter) voids in the commercially pure lead and the calcium lead, smaller voids (less than 1/8-inch diameter) in the zinc alloys, and no voids in the commercially pure zinc and 1 percent antimonial lead.

ACTIVITIES DURING THE REPORTING PERIOD

The spent fuel stabilizer prebreach disposal condition test was completed. The objective of this test was to evaluate cladding-stabilizer material interactions under expected disposal cycle conditions prior to breach of the waste canister. Information on the moisture release and gas generation behavior of the candidate stabilizer materials was also developed.

The prebreach disposal condition test unit consisted of a fuel cladding specimen (either 304 SS or Zircaloy-4) positioned in the center of a carbon steel capsule (1018 or 1020 CS). The candidate stabilizer materials are amorphous silica, quartz silica, 85 percent silica-quartz/15 percent bentonite, mullite, 85 percent mullite/15 percent bentonite, zircon, zirconia, 85 percent zirconia/15 percent bentonite, basalt, 85 percent basalt/15 percent bentonite, graphite, 1 percent antimonial lead, calcium lead, commercial lead, zinc alloy AG40A, zinc alloy AC41A, zinc-copper-titanium alloy, and commercial zinc. These materials occupied the space surrounding the cladding specimen. All candidate particulate stabilizers were given loss-on-ignition (LOI) tests to establish their moisture release behavior. All particulate stabilizers met a 1 percent moisture release criterion except for basalt and bentonite. These particulates were subsequently given thermal bake-out treatments to release the moisture and allow usage in the prebreach disposal condition tests. To fabricate test units, cladding specimens were placed in carbon steel test capsules, one per capsule. Stabilizer materials were poured into the capsules and end caps were welded. Test units were then placed in a 75 percent helium-25 percent argon gas environment where the capsule end cap vents were welded. All test units were leak-tested.

In all, 18 different stabilizer materials were placed into 36 carbon steel test capsules surrounding the 304 stainless steel and Zircaloy-4 cladding samples; 14 test capsules filled with metal alloy stabilizers and eight test capsules containing particulate-bentonite combinations were heated at 300 C; 14 test capsules containing seven different particulate stabilizers were heated at 500 C. All test units were held at the respective test temperatures for 2160 hours. After gas sampling, the capsules were cut and mounted for transverse metallographic examination. Examinations of each test capsule cross section were conducted using an electron microprobe.

Results of the electron microprobe examinations are summarized in Table 1. Although the interaction behavior of stabilizer materials with carbon steel capsules was not used as a basis for screening candidate stabilizers in this work, the results may be applicable in future considerations of canister materials. No additional penetration by the metal stabilizers into the carbon steel capsule wall occurred during the disposal condition test. In fact, no penetrations beyond 0.0005 inch were observed, whereas a 0.001-inch penetration was previously observed in the higher temperature emplacement process test. Carbon steel penetrations by particulate stabilizers after the disposal condition test were of the same magnitude (0.0001 to 0.0007 inch) as those observed with metal stabilizers (Table 1).

Only two of the seven metal stabilizer materials exhibited an interaction with the cladding samples during the disposal condition test. Extensive Zircaloy-4 wall thinning occurred with commercially pure zinc and the zinc-copper-titanium alloy (36 and 28 percent wall thinning, respectively). Detailed electron microprobe examination of the zinc stabilizer test unit revealed two distinct compositional regions of zirconium and zinc. The zirconium-zinc phase diagram reveals that three intermetallic compounds can form at relatively low zirconium concentrations in zinc. Therefore, it is concluded that wall thinning resulted from diffusion of zirconium into the zinc and formation of two intermetallic compounds. Only slight wall thinning (<0.0005 inch) occurred as the result of a 0.003-inch interaction layer on the 304 SS cladding in the zinc-copper-titanium alloy test unit (C28). Electron microprobe examination suggested the formation of a complex intermetallic compound of zinc, nickel, iron, and chromium. The interaction behavior exhibited in the metal stabilizer test units resulted in screening the commercially pure zinc and the zinc-copper-titanium alloy from further consideration as spent fuel waste package stabilizers. The other three lead alloys and two of the zinc alloys exhibited a typical noninteraction appearance.

Electron microprobe examination of test units filled with particulate stabilizers revealed an interaction with the Zircaloy-4 cladding in eight of 11 cases; however, only zirconia bentonite exhibited any interaction with the 304 SS cladding. The most extensive Zircaloy-4 interaction

Table 1. Summary of Interactions Observed in the Prebreach Disposal Condition Test.

Stabilizer	Test Unit ID	Carbon Steel Capsule (penetration, inches)	Cladding Interaction, inches	
			304 SS	Zr-4
1 Percent Antimonial Lead	C17	0.0002	None	
	C31			None
99.99 Percent Pure Lead	C19	0.0004	None	
	C32			None
Calcium Lead	C20	0.0002	None	
	C35			None
Zinc Alloy AG40A	C22	Negligible	None	
	C36			None
Zinc Alloy AC41A	C25	0.0005	None	
	C39			None
99.99 Percent Pure Zinc	C27	0.0004	None	
	C41			0.009
Zinc-Copper-Titanium Alloy	C28	0.0003	0.003	
	C42			0.007
85 Percent Mullite/15 Percent Bentonite	C91(a)	0.0005	None	
	C102			None
85 Percent Basalt/15 Percent Bentonite	C92(a)	0.0001	None	
	C103			0.0003
85 Percent Zirconia/15 Percent Bentonite	C93(a)	0.0002	0.0005	
	C104			None
85 Percent Silica-Quartz/15 Percent Bentonite	C94(a)	0.0002	None	
	C105			None
Mullite	C84(a)	0.0001	None	
	C95	0.0002		0.0005
Graphite	C85(a)	0.0004	None	
	C96	0.0003		0.0005
Basalt	C86(a)	0.0001	None	
	C97	0.0004		0.003
Zircon	C87(a)	0.0002	None	
	C98	0.0002		0.001
Zirconia	C88(a)	0.0002	None	
	C99	0.0007		0.001
Silica, Amorphous	C89(a)	0.0001	None	
	C100	0.0003		0.001
Silica, Quartz	C90(a)	0.0001	None	
	C101	0.0002		0.0004

(a) The capsule material is 1020 CS.

(0.003 inch) occurred in the test unit containing basalt. The 85 percent basalt-15 percent bentonite stabilizer exhibited an interaction an order of magnitude lower in extent (0.0003 inch), but this is due in part to the lower test temperature (300 vs 500 C). Because of interactions observed at 500 C with each of the other particulates, and the consistent high amount of gas released by the bentonite mixtures, the particulate-bentonite mixtures are also considered unsuitable for use as spent fuel stabilizers.

Mullite, basalt, zircon, and the two silica particulates each contain a form of silicon oxide as a common constituent. Because of the similarity in appearance of the interaction layer observed between these particulates and Zircaloy-4, and the brittle nature they exhibited, the interaction layer could well be a zirconium oxide. Since oxygen is evidently extracted from the silicon oxide constituents of these particulates, use of any particulate containing silica, such as sand, must be avoided.

The interaction layer of zirconia with Zircaloy-4 appeared to be brittle in nature, breaking away from the cladding. A chemical overcheck indicated approximately 5 percent HfO_2 present in this particulate. The potential exists for pick-up of oxygen by zirconium from the HfO_2 to form a zirconium oxide. If this actually occurred during the test, use of a more pure zirconia (ZrO_2) as a stabilizer cannot be precluded. Therefore, zirconia cannot be screened from consideration as a spent fuel stabilizer because the interaction observed in the zirconia disposal condition test unit may well be due to the presence of HfO_2.

The prebreach disposal condition test results provide a basis for screening all of the particulates (except pure zirconia) and two of the metal candidates (commercially pure zinc and zinc-copper-titanium) from use as spent fuel waste package stabilizers based on perceived preliminary functional and performance criteria. During the fill process test, shrinkage voids were found to be excessive for all of the zinc and lead alloys except 1 percent antimonial lead and commercially pure zinc. Therefore, based upon program results obtained thus far, pure zirconia and 1 percent antimonial lead are recommended as preliminary reference materials for spent fuel waste package designs requiring the use of a stabilizer.

FUTURE ACTIVITIES

The spent fuel waste package stabilizer preliminary recommendations will be transmitted to ONWI. Electrochemical screening tests on metal stabilizers and other waste package metallic components will continue to provide additional information for incorporating into a final recommendation on waste package stabilizers.

WBS 1.2.3

PROJECT: NBS Independent Measurement Standards Laboratory

PRINCIPAL INVESTIGATOR: National Bureau of Standards (H. T. Yolken and W. P. Reed)

ONWI PROJECT MANAGER: D. P. Moak

OBJECTIVE

The National Bureau of Standards will (1) promote, on a national and international scale, consistency and accuracy of data used in nuclear waste management; and (2) provide reference data, standard reference materials, research materials, and test methods as required. NBS may also support the DOE nuclear waste isolation program in areas outside DOE's Materials Characterization Organization and will, in accordance with established NBS policy, referee material property data and measurement procedures.

PROGRESS REPORTED PREVIOUSLY

Previous work has been devoted to establishing the program and developing the scientific goals. Significant effort has been spent on completing the literature surveys and developing scientific contacts within the nuclear waste management field. This year's focus is on understanding current scientific problems in the field of nuclear waste management, with particular emphasis on measurements standards and data.

ACTIVITIES DURING THE REPORTING PERIOD

Waste Forms Leachability Mechanisms

This task is designed to review existing efforts by others and to carry out NBS work in selected areas to improve the understanding of leaching. In addition, the effects of mechanical properties, microstructure, microchemistry, transport mechanisms, and other disruptive processes will be investigated, and support will be provided to the NBS effort on leachability of waste forms.

Phase Stability. This work continues to focus on the structural integrity of ceramic waste forms. Hollandite solid solutions in the systems $BaO:Al_2O_3:TiO$ and $BaO:SrO:MgO:TiO_2$ were investigated with respect to transformation by high-temperature X-ray methods. All materials transform from monoclinic (at room temperature) variants to tetragonal modifications at temperatures ranging from 265 to 110 C. SrO plus MgO substitutions increased at this transition temperature.

Preliminary studies were completed to evaluate the extent of Cs^+ substitution in the hollandite structure in the systems $Cs_2O:MgO:TiO_2$, $Cs_2O:Al_2O_3:TiO_2$, and $BaO:Cs_2O:Al_2O_3:TiO_2$. In the latter system approximately 20 mole percent of the BaO could be replaced by Cs_2O, with a corresponding increase of the Al_2O_3 content.

Mass Transport. Several ceramic samples of cesium hollandite and potassium hollandite were produced. These samples have a density of 80 to 90 percent of theoretical value, which is good for evaluating the transport of cesium ions in these types of structures. Impedance measurements of cesium hollandite have been made from room temperature to 800 C. Analysis of the impedance data is under way.

Mass Transport Theoretical Studies. A microscopic formulation for conducting model studies of diffusion and leaching has been developed. It is based on the use of a recurrence relation for a random walk on the lattice. This formulation is quite attractive for three reasons: (1) when the continuum limit is taken, a nonlinear diffusion equation with appropriate boundary conditions is recovered; (2) the incorporation of specific molecular mechanisms is a straightforward task; and (3) the numerical solution of the model should be easily achieved.

Mechanical Properties. Resistance of the waste form to fracture and microcracking is a potentially important property. During this quarter, the fixture for performing crack growth experiments on glasses in the gamma ray source at NBS has been completed. Baseline data taken using this fixture agreed well with literature values. These data will now be compared to those obtained in the gamma ray environment.

Plans for performing the particle recoil experiments have been formulated. Glasses have been acquired and are being machined into specimens.

Waste Form Reference Measurement Methods, Reference Materials, and Data

Development of Standardized Leach Tests. One aspect of the work investigated during this quarter involves the variable quantities of HF and HNO_3 which have been reported in the leachate and are believed to be contributed by the Teflon* PFA container as artifacts of the manufacturing and cleaning procedures, respectively. The containers are being studied for retention and release of these acids, and a possible procedure to aid in the removal of such contaminants prior to container use is being investigated.

Several other variables influencing the MCC-1 test have been identified for extensive evaluation and are currently being studied. An 8 by 23 matrix using statistically engineered glass compositions has been designed to evaluate the role of glass homogeneity in relation to leaching characteristics and the extent these homogeneity differences influence the test. Thirteen glass compositions having altered concentrations in one or more of the elements of interest are being used in these evaluations, which will include uncertainties due to sample preparation, test variability, and analytical analysis.

Also, the initial presence and subsequent diffusion into the system of CO_2 and O_2 has sparked considerable concern and discussion in the leaching community. Their variable concentrations and effect on pH and total buffer capacity, as well as the Eh of the system, have prompted isolation of the leaching cells during preparation under argon.

Finally, tests to evaluate the stability of the leachate solutions are continuing.

Research Materials for Leach Tests. The first research material, based on NBS glass K-1620, will be purchased. In addition, a series of glasses was prepared as part of the investigation to study the effect of glass composition variation on leach rate, using the MCC-1 procedure.

Development work on the second research material is continuing. Additional trial melts have been made but not yet leach tested. Two other series of samples were tested in an attempt to clarify the effect of certain parameters on the leach results obtained using the 100 C pulsating extractor described earlier. Pyrex rods having different surface finishes were run for a period of two weeks. At the end of that time, the weight loss (g/m^2) for samples finished with 320 grit silicon carbide paper was approximately an order of magnitude greater than for samples with an as-received smooth "glassy" finish.

Six different glasses were run in the extractor for a period of two weeks under a CO_2 atmosphere to determine if there is any measurable change in leach rate compared to using an N_2 atmosphere as is normally done. Preliminary results indicate decreases in leach rate for two glasses, the other being essentially the same as in the N_2 atmosphere. Further tests to verify these results are under way.

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*Certain commercial equipment, instruments, or materials are identified in this report in order to adequately specify the experimental procedure. In no case does such identification imply recommendation or endorsement by the National Bureau of Standards, nor does it imply that the material or equipment identified is necessarily the best available for the purpose.

Container, Overpacks, Sleeves, and Backfill

Container Corrosion. Initial results have been obtained using stainless steel 304 in a ground-water environment suggested by Battelle. Brine environments and titanium alloys are also being used. The electrochemical techniques include repassivation studies on flat electrode surfaces. A new electrode has been designed to study the local environment in crevice corrosion. The autoclave equipment for high-temperature experiments should arrive this quarter.

The bibliography on the corrosion of canister materials in underground environments is 75 percent complete. Work on a review of possible canister degradation mechanisms and test methods is in progress.

Backfill. The proceedings of an NBS workshop on research and development needs in backfill for nuclear waste storage in deep geologic repositories held in April will include papers on test materials, methods, and procedures used at different laboratories for evaluating backfill properties. These proceedings will also include the summary and conclusions of the informal workshop.

FUTURE ACTIVITIES

Future activities will include the development of measurement methods, standards, and data in a number of areas. Some activities in the near future will be to:

- Quantify the extent of cesium solid solution in hollandite and assess the volume change associated with the observed monoclinic to tetragonal transformation which may contribute to microfissuring of the ceramic waste form
- Develop specific solutions of the leach model for a variety of physical conditions and then suggest experiments to validate it
- Develop plans to obtain a stock of titanium and TiCode-12 metal for use in NBS tests as research materials
- Complete a bibliography and a rough draft of the review of canister degradation mechanisms
- Continue electrochemical studies on stainless steel and localized environmental characterization involving the development of crevice environments above 200 C.

WBS 1.2.4

PROJECT: Repository Waste Package Design Studies

PRINCIPAL INVESTIGATOR: Westinghouse Electric Corporation (D. Newby)

ONWI PROJECT MANAGER: J. A. Carr

OBJECTIVE

The objective of the program is to develop the preliminary designs for practical, easy-to-handle waste packages that will retain nuclear wastes for long periods of time and then effectively retard their release so that the natural barriers provided by the geology can reduce their transport to the point where they pose no threat to people and their environment.

PROGRESS REPORTED PREVIOUSLY

The contract was initiated in May 1980. Efforts in preceding quarters have been directed toward obtaining a foundation in waste package design technology, preparing the program's quality assurance plan, developing an engineered waste package system specification document, initiating waste package conceptual design efforts, and establishing and participating in interface coordination efforts with other ONWI/NWTS contractors.

A systems engineering approach was used to develop a comprehensive list of waste package functional requirements based on ONWI program criteria documents and on proposed federal regulations. These functional requirements formed the basis for the generation of design ideas which are to be matured into conceptual designs.

The Westinghouse (1980) Engineered Waste Package System Design Specification was developed and has been issued. This document defines the performance, design, and qualifications requirements that will be used to develop the conceptual and preliminary engineered waste package designs.

Functional performance descriptions were drafted for defense high-level waste (DHLW) (Form 1) and spent fuel (Form 1) in the salt geology. These documents demonstrated that the engineered waste package candidate design concepts adhered to the multiple barrier design approach and that they satisfied the functional requirements of the design specification.

A project plan for repository waste package design studies was completed.

ACTIVITIES DURING THE REPORTING PERIOD

The draft reports describing conceptual engineered waste package designs for DHLW and spent fuel (Form 1) in salt contained two basic design concepts: the borehole package design and the self-shielded package concept.

Figure 1 shows the reference design for the borehole emplacement concept. The reference design has an outermost metallic barrier (overpack) which is designed for at least a 1000-year corrosion lifetime. To meet this criterion, a relatively thin TiCode-12 (an alloy of titanium) container is required. The thickness is increased to approximately 0.64 cm (0.25 in) to ensure handling and manufacturing stability. To minimize the cost of this material, the container is reinforced with thick carbon steel. The waste form/canister is then placed inside the carbon steel overpack reinforcement, and a top cover is bolted on. The top of the outer corrosion barrier is installed over this cover and welded to form a completely sealed barrier. This package is installed in a borehole previously lined with compacted backfill to provide a total barrier with radiation shielding for operating personnel.

The self-shielded package shown in Figure 2 employs a cast overpack of sufficient thickness to attenuate the nuclear radiation at the surface to allow hands-on operations. The waste container, as received from the waste source, is placed

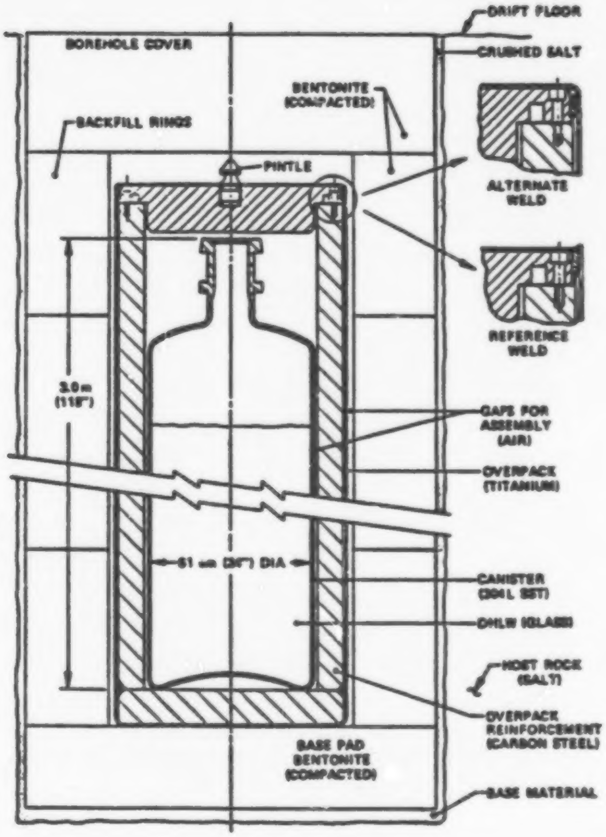
DRIFT FLOOR
CRUSHED SALT
BOREHOLE COVER
BENTONITE (COMPACTED)
BACKFILL RINGS
PINTLE
ALTERNATE WELD
REFERENCE WELD
3.0 m (118")
GAPS FOR ASSEMBLY (AIR)
OVERPACK (TITANIUM)
61 cm (24") DIA
CANISTER (304L SST)
DHLW (GLASS)
HOST ROCK (SALT)
OVERPACK REINFORCEMENT (CARBON STEEL)
BASE PAD BENTONITE (COMPACTED)
BASE MATERIAL

Figure 1. Reference Design Package for Borehole Emplacement.

into the casting, and a top shield plug is then sealed in place to form a totally leak-proof barrier. The materials being considered for this casting are grey iron, ductile (nodular) iron, and cast steel. Prior to emplacement, a layer of backfill material is placed on the floor of the emplacement tunnel. The package is then placed on this backfill, after which the emplacement tunnel can be backfilled.

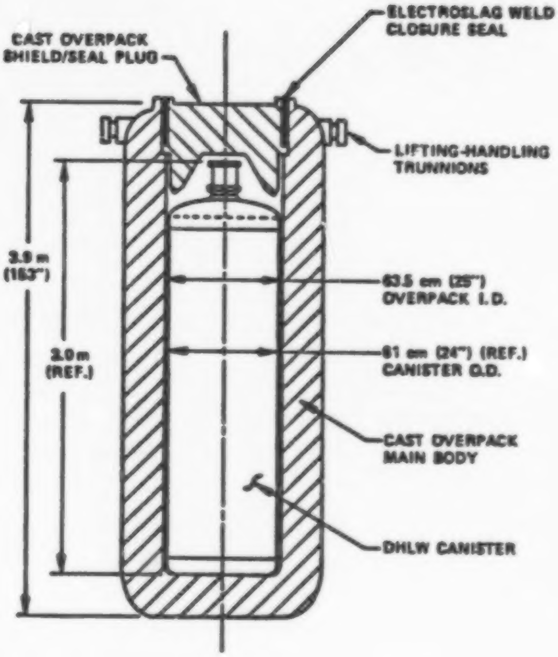
CAST OVERPACK SHIELD/SEAL PLUG
ELECTROSLAG WELD CLOSURE SEAL
LIFTING-HANDLING TRUNNIONS
3.9 m (153")
3.0 m (REF.)
63.5 cm (25") OVERPACK I.D.
61 cm (24") (REF.) CANISTER O.D.
CAST OVERPACK MAIN BODY
DHLW CANISTER

Figure 2. Self-Shielded Containerized Package.

The principal inherent advantage to the self-shielded package is safety. Most operations are performed hands-on, and the package can take abuse during handling with little or no consequence. Large internal clearances can be allowed, thereby permitting generous tolerances for the waste production processes. The self-shielded package also allows waste packaging hot cell facilities at the repository to be minimized, since the only operation with a hot cell is transfer of the waste canister from a shipping cask into the package and installation of a shield/seal plug. Package sealing operations will be hands-on. Other facility savings at the repository are the elimination of shielded lag storage facilities and the shielded, remotely operated transfer and emplacement equipment.

There are potential savings if the self-shielded package is used for shipping between sites. These advantages would make the total system safer, since transfer of unshielded material would occur once at the waste source and any problems with packaging would be taken care of at the source. Further, the necessity for large, air-cooled interim storage facilities could be eliminated.

An internal review committee did not find any major deficiencies that would result in the inability to successfully develop the reference conceptual design.

At a design review on the DHLW and spent fuel conceptual designs in salt, it was concluded that the designs presented were responsive to the requirements, although discussion continues as to the merits of backfill. Agreement was reached to discontinue effort on the redundant metallic barrier approach. A design review report was prepared.

The interface information in the waste package design specification (Westinghouse, 1980) was upgraded to reflect the latest waste form, geology, and repository data.

Efforts were initiated on preparing plans to describe the development programs necessary to (1) confirm conceptual design feasibility and (2) compare package designs to determine the best design.

A decision tree approach was selected to guide the economic comparison of design concepts. This approach has been described and implemented with illustrative waste disposal system examples. In parallel, a rudimentary technical modeling approach covering performance, safety, and licensability is in preparation as an additional mechanism to compare design concepts.

The number of conceptual design reports and design reviews has been reduced by 75 percent. As part of this change in scope, argillaceous will no longer be considered as a candidate geology.

The development of conceptual package designs for commercial high-level waste (CHLW), DHLW, and spent fuel (Form 2) in basalt and spent fuel (Form 2) and CHLW in salt is proceeding satisfactorily. Major design decisions have been made with respect to backfill, metallic corrosion rates, shielding, and the manufacturing process for the titanium overpack in the borehole design.

Discussions have continued to determine the proper interface data for CHLW and DHLW and backfill operating parameters. Of special interest is the maximum temperature.

FUTURE ACTIVITIES

During the next quarter, the conceptual designs for DHLW, CHLW, and spent fuel (Form 2) will be completed, and a report will be drafted.

Draft reports describing plans that give the development programs necessary to (1) confirm conceptual design feasibility and (2) compare package designs to determine the best design will be issued.

REFERENCE

Westinghouse Electric Corporation Advanced Energy Systems Division, 1980. Engineered Waste Package System Design Specification, AESD-TME-3055, Pittsburgh, PA.

WBS 1.2.4

PROJECT: Design Specification Support

PRINCIPAL INVESTIGATOR: Battelle Columbus Laboratories (N. E. Miller)

ONWI PROJECT MANAGER: J. A. Carr

TASK 1: DOCUMENT SEARCH AND EVALUATION

OBJECTIVE

The objective of this task has been to gather and review documents and reports applicable to the design effort on spent fuel and high-level waste packages and to prepare an annotated bibliography for the waste package designer to use.

PROGRESS REPORTED PREVIOUSLY

This task began in May, 1980. Over 1,200 references were identified by manual and computerized searches. Approximately 1,000 of these citations were reviewed, and about 450, identified as being potentially useful to the waste package designer, were abstracted. The references and abstracts, arranged by subject categories, were included in the draft of the annotated bibliography document submitted for review.

ACTIVITIES DURING THE REPORTING PERIOD

The final report, an annotated bibliography for the design of waste packages for geologic disposal of spent fuel and high-level waste, has been submitted.

TASK 2: CRITERIA COMPLIANCE EVALUATIONS

OBJECTIVE

The objective of this task is to evaluate two waste package conceptual design reports prepared for compliance with the NWTS waste package criteria.

PROGRESS REPORTED PREVIOUSLY

This task was begun during this reporting period.

ACTIVITIES DURING THE REPORTING PERIOD

Draft reports on engineered waste package conceptual designs for defense high-level waste (borosilicate glass with SRL Defense Waste Processing Facility dimensions and production parameters) and spent fuel (whole assemblies) for disposal in salt were received for review. These two reports were evaluated for compliance with the NWTS draft waste package system performance criteria and another draft on waste package performance criteria.

The results of the evaluation of the reports were presented in a draft. In general, the reports were found to be in compliance with the NWTS criteria.

FUTURE ACTIVITIES

A final report on this task will be submitted.

TASK 3: TECHNICAL ASSISTANCE

OBJECTIVE

The objective of this task is to provide technical assistance to the ONWI staff in preparing draft documents for waste form and waste package specifications.

PROGRESS REPORTED PREVIOUSLY

This task began during this reporting period.

ACTIVITIES DURING THE REPORTING PERIOD

Two draft specification documents were prepared in a format paralleling that of the waste package performance criteria, but providing more detailed and quantitative requirements under each of the subcriteria headings.

The first document on waste form performance specifications and data requirements should (1) supply requirements to the waste form producers as to acceptable waste forms for geologic disposal and (2) assist in the waste form selection process. This draft document was submitted to ONWI and revised as a review draft document.

The second document on waste package performance specifications and data requirements is planned to provide a basis for waste package design efforts in a format similar to the waste form specification.

FUTURE ACTIVITIES

Final drafts of the two documents will be prepared, pending receipt of comments.

WBS 1.2.5

PROJECT: Waste Package Performance Evaluation

PRINCIPAL INVESTIGATOR: Science Applications, Inc. (D. H. Lester)

ONWI PROJECT MANAGER: H. C. Burkholder

OBJECTIVE

Under previous projects, various engineered barrier concepts for geologic isolation have been analyzed to model waste package degradation and nuclide release. The objective of this study is to modify these existing waste performance models for particular radioactive waste and package designs and to evaluate the packages' lifetimes and radionuclide release rates and concentrations at the package-repository boundary as functions of time.

This project interfaces with Repository Waste Package Design Studies, WBS 1.2.4, to develop conceptual, and later detailed, designs for waste packages. The two projects are initial efforts to develop and qualify waste packages for the waste isolation system.

PROGRESS REPORTED PREVIOUSLY

This project was started on 23 February, 1981. The previous report discussed planned changes to the BARIER code to prepare for the performance evaluation work. Four types of code modification were planned.

- Housekeeping changes to improve the convenience and efficiency of the code
- Data base revision to accommodate new materials and repository conditions
- Correction of errors found in the old version
- Conceptual model versions such as dual corrosion mechanisms (local and bulk), high hydrostatic pressures, and substantial changes to the nuclide release model.

ACTIVITIES DURING THE REPORTING PERIOD

Activities during the quarter included completion of code modifications and sensitivity studies to help review the planned matrix of variables for case studies.

The package degradation and failure portion of the code has been revised to accommodate dual mode corrosion. Local corrosion contributes to the development of leaks but not to a reduction of wall strength. Wall strength is reduced by bulk corrosion. The model now handles the situation where more than one barrier element can be wetted at the same time (the outer barrier leaked but did not fail, the liner barrier underwent corrosion simultaneously with the outer barrier). TiCode-12 has been added to the data base for corrosion, and some other changes have been made to corrosion rates based on additional data recently obtained. The corrosion rate model has been coupled to the radiation level by way of a multiplier which depends on the dose rate (R/hr) at a particular barrier. Based on the reference repository conditions documents (ONWI drafts), a hard rock repository hydrostatic pressure of 450 psi (3.1 MPa) and salt repository hydrostatic pressure of 850 psi (5.9 MPa) will be used in the calculation. Lithostatic pressure in the salt repository will be 2800 psi (19.3 MPa).

The temperature subroutines have been revised to give a temperature profile in the package rather than the temperature of one barrier. This was needed since multiple barriers are now tracked in time (see above).

A detailed output option has been added, allowing a time map of events so that intermediate states can be examined. This was mainly added to facilitate debugging but is useful for studying package behavior in some cases.

Three coding errors discussed during review of the old BARIER have been fixed in the STRESS subroutine. One was the yield criterion discussed previously; the other two are as follows:

- The expressions for V* ("VSTAR" in the code) had a 2A under the square root which should have been A^2.
- The expression for P1 ("EPRESS" in the code) contained R3 squared when it should only have been to the first power.

The nuclide release subroutine has been substantially changed. Key changes include:

- Inclusion of radiodecay during transport through the backfill
- Extension of results to the entire discharge period ("tail-off" was not previously calculated)
- A special routine for transport resistance with no backfill capacity
- Provision for output of the concentration at the package-geology interface as a function of time
- Changes to accommodate a new list of nuclides (^{90}Sr, ^{99}Tc, ^{226}Ra, ^{237}Np, ^{238}U).

Sensitivity studies were done to determine the sensitivity of the release model to many parameters and to do extensive checking (some errors were found). Some calculations in the degradation model were also done to determine if the original run matrix was appropriate. No changes are anticipated.

FUTURE ACTIVITIES

Final checking and documentation of the revised BARIER code is in progress and will be completed during the next quarter. Performance evaluation runs will be made and reported for the four package concepts being considered. A project final report will be prepared.

WBS 1.2.5

PROJECT: High-Level Waste Form Preparation (HLWFP)

PRINCIPAL INVESTIGATOR: Pacific Northwest Laboratory (D. H. Siemens)

ONWI PROJECT MANAGER: J. A. Carr

OBJECTIVE

The objective of this program is to characterize, prepare, and ship the Nuclear Waste Vitrification Project (NWVP) #2 waste log to the EMAD Facility. At EMAD, the waste log will be sealed in a storage canister and then shipped to Hanford, Washington, for storage in the Near-Surface Test Facility.

PROGRESS REPORTED PREVIOUSLY

Characterization and preparation of the waste log for shipping were completed. All equipment required for handling the shipping cask and shipping the log to EMAD was designed. Fabrication of these items was in progress.

ACTIVITIES DURING THE REPORTING PERIOD

All of the cask-handling and shipping hardware has been fabricated and accepted. A special bail was added to the required hardware, which in turn was attached to the waste log to enable EMAD to remove the waste log with their existing BWR grapple.

The cask-handling procedure is complete and approved. All training in reference to this program is complete.

The PNL Operation Readiness Plan is complete and approved. This plan was reviewed by an Operation Readiness Review Board, and no significant changes were required.

FUTURE ACTIVITIES

A dry run on the cask-handling equipment will be performed, and then the NWVP #2 waste log will be loaded and shipped to EMAD.

A letter report will be issued on the findings of the characterization efforts, and a final report will be made at the conclusion of the program.

WBS 1.2.5

PROJECT: Cooperative Field Tests in Salt

PRINCIPAL INVESTIGATOR: Sandia National Laboratories (T. O. Hunter)

ONWI PROJECT MANAGER: A. J. Coyle

OBJECTIVE

This project supports the collection of field test data necessary for Repository Data Base Development for salt, specifically by (1) providing management support for field testing activities, (2) evaluating and improving existing techniques for in situ rock characterization, (3) performing experiments in southeastern New Mexico (SENM) that address issues identified in the repository development program, and (4) supporting the international cooperative program on nuclear waste management.

ACTIVITIES DURING THE REPORTING PERIOD

Radar scanning experiments were conducted at the Avery Island and SENM mines. The modified radar detected air-salt interfaces, previously buried metal targets, and brine pockets. This is an important breakthrough since the new radar system will permit detection of pressurized gas pockets in salt and consequently make the mining operation safer in preventing blowouts.

Thermomechanical computer codes were compared with the FRG ANSALT code. The results compared favorably with U.S. calculations.

Thermal probe results obtained at Avery Island are being analyzed, and a final report is in preparation.

Data collection for stress gages at the Avery Island heater experiment is continuing.

WBS 1.2.5

PROJECT: Thermal Gradient Brine Migration

PRINCIPAL INVESTIGATOR: University of California (D. R. Olander)

ONWI PROJECT MANAGER: G. E. Raines

OBJECTIVE

The objective of this investigation is to develop a rigorous model of thermal gradient brine migration in natural rock salt.

PROGRESS REPORTED PREVIOUSLY

This study was started on 1 July, 1979.

All-Liquid Inclusions

There are two basic features of the migration behavior of all-liquid inclusions in synthetic single crystals: (1) the rate-controlling step is associated with the kinetics of dissolution at the hot face, and (2) dislocations provide the necessary imperfections needed to permit dissolution. This has been supported by the results of migration experiments in KCl and NaCl single crystals in a temperature gradient. The velocity was found to vary as the temperature gradient raised to a power >2. In order to explain these results, a detailed theoretical model has been proposed, based on the Burton-Cabrera-Frank theory of crystal growth as applied to dissolution. An attempt is currently under way to apply these ideas to modeling the migration behavior in natural rock salt.

Gas-Liquid Inclusions

The objective of this part of the work is to adapt the model of thermocapillarity-driven flows to the brine migration process. The previous report presented the following achievements:

1. An existing numerical analysis of a hemispherical noncondensible gas bubble placed on a flat heated surface has been modified to include mass transfer across the bubble interface;
2. A numerical solution to the diffusion-convection equation for diffusion of salt in the liquid shell has been worked out for a symmetric bubble location in a spherical inclusion. The solution is intended to check the accuracy of the perturbation solution presented in ONWI-208 (Olander, Machiels, and Yagnik, 1980).

ACTIVITIES DURING THE REPORTING PERIOD

All-Liquid Inclusions

The principal objectives were to study the migration behavior of these two types of inclusions:

1. Inclusions of their own brines in KCl (100) single crystals at higher axial loads;
2. Mixed-brine inclusions (1 M $SrCl_2$) in NaCl (100) single crystals and in natural rock salt.

The experiments in (1) have been completed, and the results have been analyzed. The data show that for a given temperature and temperature gradient, the migration velocities increased with increasing axial load as compared with the case of zero axial load. The velocities reached the diffusion-controlled limit and followed approximately linear interface kinetics. Finally, the velocities remained at the higher level even after the load was removed.

These observations are in agreement with predictions based on the effects of dislocation densities on the crystallization-dissolution process. A preliminary model, based on the Burton-Cabrera-Frank theory of crystal growth, was presented earlier. This has now been carefully reconsidered and refined to account for the observed effects.

The experiments in category (2) are still in progress with the NaCl single crystals; those with the natural rock salt have only just begun. Thus, no results are being reported at this time. In parallel with the experimental work, however, the theoretical ideas generated from the single crystal work are being refined to include the effects of grain boundaries in the natural rock salt.

Gas-Liquid Inclusions

The objectives were to adapt the numerical analysis of the hemispherical gas bubble to the brine migration process and to develop numerical algorithms for computation. Along these lines work was carried out as follows:

The original computer program for a hemispherical bubble in an infinite extent of liquid was modified to a hemispherical enclosure and to include concentration effects. Thus the program, as it stands presently, solves the coupled mass, momentum, and energy equations in the hemispherical enclosure of liquid, with the bubble centered on the flat surface. The mass interchange process at the bubble interface retains the characteristics of the previous approach, that is, an accommodation coefficient accounting for the variations in vapor concentration, while the temperature difference between the liquid at the interface and the bulk of the gas is the driving force for mass transfer.

After establishing that the program was running correctly, a parametric analysis of the Biot number at the bubble interface was performed. The range of Biot numbers that were physically compatible with previous studies reported in ONWI-208 has been determined to be 0.5 to 1.0. Higher values tend to produce strong concentration effects, reversing the flow at the bubble interface. Smaller values produce the same behavior as all-liquid inclusions. Similar analyses were performed for several of the nondimensional groups intervening in the problem. Detailed analyses of these results will be presented in a topical report on this study.

An interesting feature disclosed by this investigation for the physical conditions prevailing in the laboratory experiments (ONWI-208) was the significance of high values of the Schmidt number compared with the Prandtl number. This results in extremely slow variations of the concentration, due to the elevated inertial effects, which causes excessive computing time to achieve asymptotic, steady state behavior.

The speed of the gas-liquid inclusions predicted by this investigation compares well with the experimental results reported in ONWI-208.

The development of numerical algorithms for the spherical liquid inclusion with a centrally positioned spherical gas bubble is complete for the decoupled temperature effects (i.e., gravity effects are not considered, and the momentum equation is decoupled from the energy equation). Temperature distributions from these numerical evaluations compare closely with the analytical predictions from ONWI-208. As in the ONWI-208 analytical study, analytical velocity fields were used as input to the computer programs.

Numerical algorithms for evaluating the velocity field in the inclusion are ready to be verified. Their incorporation will allow extending the study beyond the restriction of the ONWI-208 analytical solutions which are limited to small perturbation conditions.

FUTURE ACTIVITIES

Experiments with the natural rock salt will be continued. The results will be compared with predictions from the theoretical modeling work. This phase of the work will be completed with the preparation of the topical report.

The hemispherical enclosure study will be completed with the preparation of the topical report, in which the influence of physical parameters will be demonstrated and results will be compared with available experimental data.

In the spherical enclosure study, the correctness of the numerical algorithms for the solution of the coupled mass, momentum, and energy equations will be established. The accuracy of the solutions will be assessed and the results compared to the analytical and experimental results from ONWI-208 and more recent ones.

REFERENCE

Olander, D. R., A. J. Machiels, and S. K. Yagnik, 1980. Thermal Gradient Migration of Brine Inclusions in Salt, ONWI-208, Office of Nuclear Waste Isolation, Battelle Memorial Institute, Columbus, OH, October.

SUMMARY

1.3 SITE

The objective of the Site Task is to identify and characterize sites within the contiguous United States that are suitable for construction and operation of a mined geologic repository for the long-term isolation of radioactive waste. Site investigations involve developing siting criteria and identifying and screening media and geosystems using these criteria. Evaluation of these media is being carried out by relating them to the U.S. DOE (1981) NWTS program criteria document. These evaluations are currently in various stages of the screening process.

The Bendix Field Engineering Corporation study team concentrated activities on systems analysis and data definition/acquisition processes for the site characterization data base scoping study. Nearly 300 data elements were defined and classified, all pertaining to technical disciplines involved in site characterization.

Laboratory observations of diagenetic alterations of the Conasauga shale suggest that in a HLW repository in shale, the increased temperature may cause the crystallization of chlorite, quartz, and/or calcite in the small tension fracture caused by the excavation, producing a self-healing process that will decrease fracture porosity and permeability.

Several Hanford region ground-water samples were collected. These few data are not currently amenable to interpretation because of confusing results for some samples, for which duplicate analyses are needed. For at least one moderately deep sample, a ground-water age of 250,000 years or more is comparable with the data.

The basic design of the equipment used to collect helium for dating ground water has been changed. The new design calls for collecting only a water sample at a pressure above that of effervescence.

For ^{36}Cl dating of ground water it is important to know the input ratios of ^{36}Cl to total Cl. This has been done for the United States. Preliminary interpretation of ^{36}Cl/^{37}Cl data for the Milk River aquifer in southern Alberta, Canada, suggests that it will be possible to use chloride isotopic data to distinguish between the mechanisms of ion filtration, megadispersion, and diffusive transport.

A hyperfiltration test on montmorillonite is in progress, and it appears that both the osmotic efficiency and back diffusion of salt can be measured.

In the Paradox Basin, primary effort was directed toward preparing the five-volume area characterization report, laboratory analysis of core samples from the Salt Valley and Gibson Dome boreholes, and re-entry of the existing Kubat hole. Operations at the Kubat hole reached a depth of 3,000 feet. Procurement activities associated with the drilling of the Elk Ridge No. 1 borehole and the long-term hydrological testing of the Gibson Dome No. 1 hole were initiated.

Portions of the Permian Basin study area meeting preliminary screening specifications were identified and recommended for further investigation. Drilling of a stratigraphic test well in Donley County, Texas, began. The Texas Bureau of Economic Geology completed detailed stratigraphic cross sections of the Upper Permian, Triassic, and Tertiary strata in the Palo Duro Basin and continued other topical investigations.

The salt dome site characterization planning effort has centered on meetings in Texas, Louisiana, and Mississippi to discuss key issues of concern. These issues were identified by the states as requiring resolution to allow screening from four to one domes for detailed site characterization.

The USGS has discussed programs in Louisiana and Mississippi which will address the regional hydrology around Vacherie, Richton, and Cypress Creek Salt Domes. The program will be carried out over several years.

Several studies in the Paradox Basin were initiated by Bechtel, including: (1) preliminary socioeconomic impacts of an exploratory shaft and repository on Southeastern Utah; (2) probable maximum flood in Gibson Dome study area; (3) preliminary evaluation of potential deterioration of air quality in Gibson Dome study area from activities associated with an exploratory shaft and a repository; and (4) endangered/threatened species field survey of the Gibson Dome and Elk Ridge study areas.

Studies dealing with the development of domes and salt basins continued. These, along with studies on caprock formation and internal dome structure, will contribute greatly to an expanded understanding of salt domes, salt basins, and their history and development.

Pacific Northwest Laboratories continued gathering baseline environmental data in the Northeast region. Meetings were held with Argonne National Laboratory (performing the Northeast geologic characterization), wherein agreement was reached on the boundaries of the study region.

Oak Ridge National Laboratory completed gathering about 95 percent of the required environmental baseline data for the Southeast region. Ecosystem, water resources, climatic data, land use, and demographic data bases are complete and adequate for characterizing the regional environment.

Work is being conducted in the Lake Superior region to identify potentially suitable crystalline rock bodies through a study of existing literature. Argonne National Laboratory continued to integrate and analyze environmental data gathered for a portion of the region. A summary environmental characterization is in the latter stages of preparation.

In the Morro do Ferro thorium deposit in Brazil, thorium was found to be contained in zircon, monazite, and cheralite, a monazite-like mineral. Thorium is a major constituent of cheralite, being up to about 30 percent of the mineral, and cheralite appears to be the dominant host for thorium.

An evaluation of the theoretical relative stability of thorium (+4) and plutonium (+4) complexes suggests that in the probable aqueous chemical environment in Morro do Ferro, thorium and plutonium will behave in a rather similar fashion.

The behavior of a nuclide of concern to nuclear waste isolation, ^{137}Cs, will be studied in samples from the natural fission reactor, Oklo, using samples from Reactor Zone 9. For this purpose, mass spectrometry for high precision measurements of barium isotopic ratios is necessary and has been developed, tested, and found to be adequate.

REFERENCE

U.S. Department of Energy, 1981. NWTS Program Criteria for Mined Geologic Disposal of Nuclear Waste: Site Performance Criteria, DOE/NWTS-33(2), Office of NWTS Integration, Battelle Memorial Institute, Columbus, OH.

WBS 1.3.1

PROJECT: Site Characterization Data Base Scoping Study

PRINCIPAL INVESTIGATOR: GJO/Bendix Field Engineering Corporation (M. B. Evans)

ONWI PROJECT MANAGER: N. J. Beskid

OBJECTIVE

The objectives of this project are to define system requirements and to specify detailed design objectives for a computer-based nuclear waste storage site characterization data base using conventional systems analysis and data-gathering methods. The data base would contain all characterization data collected at the various study levels: regional, area, and site-specific characteristics of a deep geologic repository. The data base system must satisfy (1) the need to coordinate the accelerated field data collection expected in the years 1980-85 and to accept and store these data retrievably, using quality assured methods; (2) the requirement for efficient information retrieval, suited to the volume and nature of the various data--geologic, hydrologic, environmental, and socioeconomic parameters for each region, area, and potential repository site; and (3) the ability to periodically update the data, when properly disposed within the data base within the extended time frame which is expected for site characterization and licensing sequences for repositories.

PROGRESS REPORTED PREVIOUSLY

This project began in April, 1981; therefore, this is the first quarterly technical progress reported.

ACTIVITIES DURING THE REPORTING PERIOD

The technical activities during the reporting period all concentrated upon systems analysis and data definition and acquisition processes.

During the period, 272 data elements were defined, classified, and entered into the Data Dictionary. These data elements pertain to the technical disciplines (e.g., geology, hydrology, and demography) which are involved in site characterization. All these disciplines have been addressed except for rock mechanics and meteorology. A computer process for indexing the Data Dictionary using keyword-in-context and keyword-out-of-context has been initiated.

FUTURE ACTIVITIES

The first draft of the Data Dictionary will be completed, as will be a draft on the system requirements.

WBS 1.3.2

PROJECT: Acoustic Studies in Climax Stock

PRINCIPAL INVESTIGATOR: Lawrence Berkeley Laboratory (E. Majer)

ONWI PROJECT MANAGER: A. Andrews

OBJECTIVE

The experiment seeks to develop and evaluate techniques for monitoring the integrity of nuclear waste repositories and to determine the suitability of granite or hard rock as a repository medium. Microseismic (MS), acoustic emission (AE), and waveform analysis techniques are employed at the Nevada Test Site to study the relationship between discrete rock failure and stress release relative to thermal effects, radiation degradation, mine geometry, and canister spacing.

PROGRESS REPORTED PREVIOUSLY

The experiment began in December 1979. Acoustic emission sensors (piezoelectric crystals) were deployed in a 15-station, three-dimensional array centered on a canister drift that would eventually house spent fuel. Three months of monitoring prior to waste emplacement and heater turn-on and several months following brought about these findings:

1. The repository rock has P- and S-wave velocities typical for granite.
2. Seismic frequencies between 1 and 10 kHz indicate that the rock is not homogeneous. Ongoing observations of these properties may offer a means of mapping the progress of fracture zones or zones of alteration.
3. Approximately one to three discrete seismic events occur each week within the mine structure, but they are not associated with the canister area. These events are presumably in response to stresses induced by mining, drilling, and coring.
4. There was no evidence that strong ground motion within the repository, associated with nearby underground nuclear explosions, induces cracking or otherwise enhances the microfracturing process.
5. After waste emplacement and heater turn-on, AE/MS activity was detected near canisters 11 through 15. The main effect seemed to be in the concrete floor above the waste canisters.
6. Except for one period of high activity, AE/MS activity decreased to less than one event per week, and later decreased further to one event per month. Velocity and attenuation measurements using active acoustic sources were started to determine changes in rock properties. Attenuation measurements seem much more sensitive than velocity measurements. Relative S-wave to P-wave amplitudes indicate a dewatering of the rock in heated zones.
7. The Qs/Qp (where Q designates specific attenuation) ratio continued to increase.

ACTIVITIES DURING THE REPORTING PERIOD

AE and P- and S-wave velocity and amplitude measurements continued. AE activity stayed nearly constant at one event per month. The activity seemed to have no relation to the heating of the rock. The few events detected were located in zones not yet heated by the canisters (Figure 1).

The S-wave amplitude/P-wave amplitude continued to increase. This is probably in response to drying of the rock due to the increased temperature and expansion of the rock (Figure 2).

The main effort on the project has shifted to improving the techniques and equipment for monitoring AE activity. The automated seismic processor (ASP) is being upgraded in a two-stage process for improved computing speed and output time. The first stage is to install an arithmetic processor chip to improve arithmetic calculations by a factor of 20. Also being incorporated is a cassette tape recorder to replace the printer now being used for output. With these two improvements, the turn-around time will be a maximum of 1 minute with full detection on 15 stations and using full processing.

The second stage in ASP upgrading is the addition of an LSI 11-2 microcomputer. This will not only increase speed but also improve the processing power of the ASP. Included in the new processing will be an automated fault plane solution using moment tensor analysis (from max amplitudes and first-motion data) and an improved location program using a velocity gradient model.

FUTURE ACTIVITIES

AE/MS and waveform monitoring will continue through FY 81. Software development will also continue with the commencement of the final debugging process.

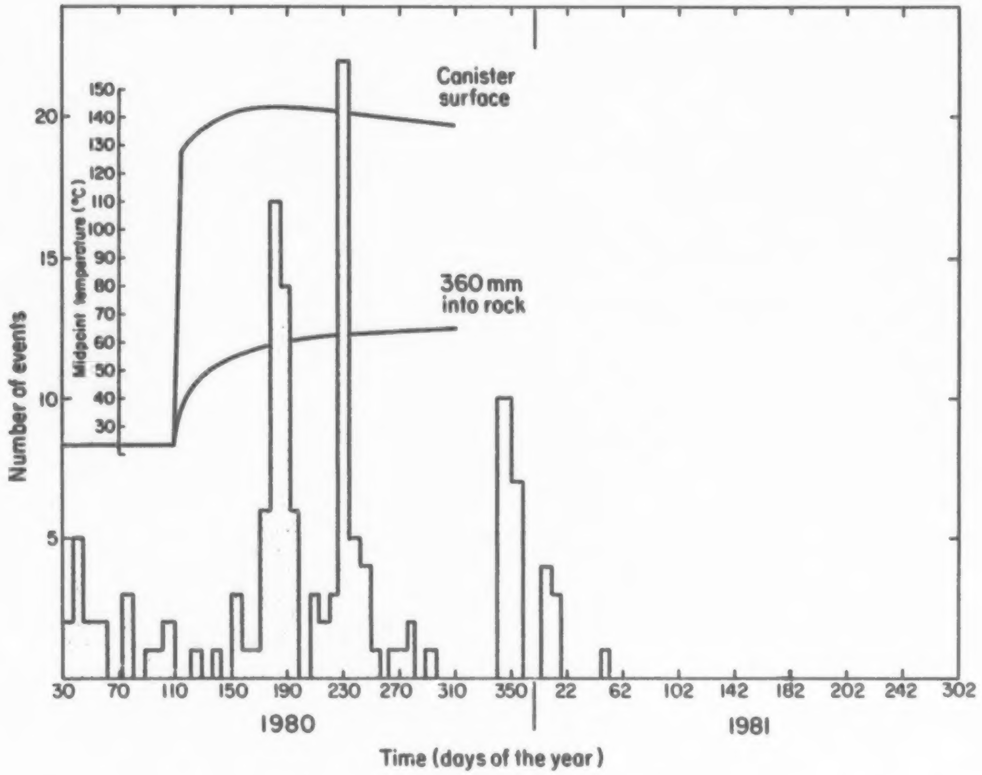

Figure 1. Acoustic Emission Activity During 1980 and the First Half of 1981.

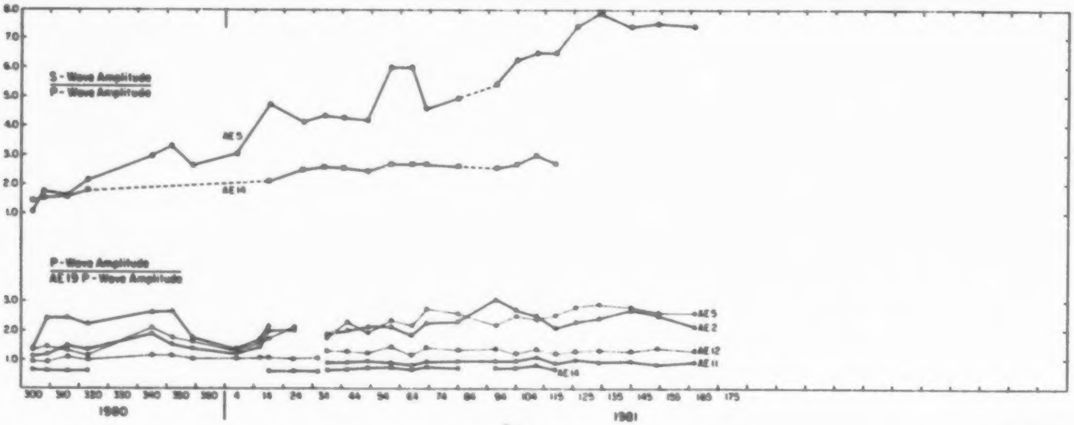

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Figure 2. Diagrammatic View of Increase of S-Wave Amplitude/P-Wave Amplitude Across Heated Regions.

WBS 1.3.2

PROJECT: Shale Structure Studies

PRINCIPAL INVESTIGATOR: Georgia Institute of Technology (C. E. Weaver)

ONWI PROJECT MANAGER: N. Hubbard

OBJECTIVE

One objective is to develop geothermometry methods to determine the maximum temperature to which shales have been subjected during their burial history to determine the past thermal history of shales and evaluate which would be best suited for a HLW repository site. Another objective is to determine what changes and processes took place in shales that were subjected to burial temperatures in the range of 50 to 400 C to predict what changes and processes would occur in shales if they were exposed to heat generated in a HLW repository.

PROGRESS REPORTED PREVIOUSLY

The project began in February 1977. A suite of Cambrian Conasauga shale samples subjected to varying burial temperatures was collected from the ridge and valley province of Georgia, Tennessee, and Alabama. Nearly all mineralogical, chemical, isotopic, petrographic, and structural parameters systematically change from the northwest to the southeast. The changes coincide with increasing depth of maximum burial and therefore with increasing burial temperature. Isotopic temperatures based on the ^{18}O content of illite and quartz, and temperatures estimated on the basis of color alteration of phosphatic fossil fragments, indicate that the burial temperatures range from about 150 to 475 C. Such parameters as illite and chlorite crystallinity, composition of illite and chlorite, 1Md/2M ratio, percentage of expandable layers, potassium-argon apparent age, orientation, flake size, formation of new minerals, etc., vary as a function of increasing temperature. Diagenetic changes occur in the illite, chlorite, quartz, carbonate, feldspar, kaolinite, and mixed layer clay.

The illite-mica in samples from the early diagenesis stage (<150 C) occurs as discrete flakes and plates. Throughout the stages of diagenesis (150 to 250 C), anchimetamorphism (250 to 425 C), and early epimetamorphism (>425 C), this shape is maintained although the crystals become larger by either growth or aggregation. At 250 C slaty cleavage starts to develop by rotation and crystallization, and lenticular domains of chlorite, phengite, and white mica are developed. With increased temperature the lenticular domains are destroyed by pressure solution.

ACTIVITIES DURING THE REPORTING PERIOD

Scanning electron microscope (SEM) studies confirm the rotational origin of the slaty cleavage and provide information on how the chlorite pods develop. During the early stages of metamorphism, most of the larger flakes are oriented at an angle ranging from 30 to 90 degrees to the slaty cleavage. Chlorite pods have approximately the same length (50 μm) as the large mica flakes. Much of the finer grained illite is highly distorted and kinked. The kinks and folds are mostly small, commonly ranging from 5 to 20 μm in length. These contortions are determined in part by the presence of quartz grains, but the axial planes are aligned in the general direction of the main cleavage. Many more fine flakes are oriented parallel to the major cleavage than are the coarser flakes. The crenulations indicate that most of the slaty cleavage was developed by rotation of the smaller flakes.

If a mixture of parallel-oriented coarse mica flakes and fine illite flakes is subjected to a stress parallel to the 001 plane, the illite flakes first tend to move by slipping along the 001 plane. Wherever barriers (quartz, carbonate, mica flakes) are encountered, the illite flakes pile up and cause the large mica flakes to rotate.

Some of the illite flakes assume the same orientation as the mica flakes. This is commonly observed. At some stage slippage no longer accommodates the applied stress and buckling and kinking occur. At this stage crystallization along the axial plane of the kinks can occur. This does not appear to be a major feature in the Conasauga. Most of the new mineral growth appears to be associated with large flakes and pods rather than in the cleavage lamellae.

SEM pictures indicate that the chlorite pods altered from mica, largely biotite, apparently in areas of high stress and where there was the potential for void space to develop, i.e., small folds (slippage), splayed books, and areas supported by a framework of rigid grains. Once chlorite growth started in small voids, continued stress caused the voids to reopen and growth of the chlorite continued until the chlorite pod was aligned perpendicular to the direction of stress.

One objective is to differentiate between the effects of thermal and dynamic stress. To a large extent, temperature will determine which minerals will be destroyed and which will crystallize. Dynamic stress determines where solution and crystallization will occur. Solution or diffusion will normally occur in high stress areas and crystallization in low stress areas. In a HLW repository thermal effects will predominate but the dynamic stress field will be altered during excavation. The increased temperature may cause the crystallization of chlorite, quartz, and/or calcite. It is likely that most of this material will be deposited in the small tension fractures caused by excavation. A self-healing process would be created, and fracture porosity and permeability would be decreased. Thus, the heat generated by HLW could be an asset in a shale repository.

FUTURE ACTIVITIES

Synthesis of the Conasauga data will conti Some salt samples have been collected, and techniques will be developed to concentrate on the nonhalite minerals.

WBS 1.3.2

PROJECT: Thermodynamic Properties of Actinides

PRINCIPAL INVESTIGATOR: Lawrence Berkeley Laboratory (N. Edelstein)

ONWI PROJECT MANAGER: J. B. Moody

OBJECTIVE

The program is investigating the thermodynamic properties of anticipated actinide and fission product ions and the compounds they may form in geologic environments so that their chemical behavior and potential migration in a nuclear waste setting can be assessed with improved capability.

PROGRESS REPORTED PREVIOUSLY

This project started in FY 79. Since that time, electrochemical methods for determining stability constants of trace metals have been developed and tested on model systems. Equipment suited for studies on actinides has been designed and constructed, and the electrochemical procedure has been tested in the radiochemical isolation box.

Additionally, techniques using photoacoustic spectroscopy have been developed to detect trace lanthanide ions, especially Nd^{+3}. The laser-based equipment has been designed, constructed, and tested on dilute aqueous solutions.

Studies of metal complexation with hydroxide have been performed using nonlinear least-squares fitting of data obtained in potentiometric titrations of metal ions with base.

ACTIVITIES DURING THE REPORTING PERIOD

Experimental Survey of the Electrochemical Properties of the Actinides

Studies of Np(IV) continued during the past quarter. In acidic solution no reduction was observed using linear scan voltammetry, but an oxidation wave occurred. The oxidation wave was linear in Np(IV) concentration, but was not dependent on the time allowed for deposition of neptunium species, as determined by anodic stripping voltammetry.

The oxidation wave was found to be a nearly reversible, one-electron process suggesting a $Np(III) \rightarrow Np(IV) + e^-$ reaction. It is probably not due to impurities, as a spark spectrograph analysis showed negligible impurities capable of electroactive behavior. The Np(III) is believed to be reduced at the electrode after a Np(IV) species is adsorbed. In support of this, it was observed that the reaction only occurs on mercury electrodes (not on glassy carbon, where sorption is much less) and that the wave height is increased in chloride media relative to nitrate or perchlorate media. The shape of the waves generated is typical of diffusion-limited oxidation waves. Np(IV) could be determined in this manner at concentrations ranging from 1.2×10^{-5} M to 2.3×10^{-4} M, an order of magnitude better than previous electrochemical methods

In basic solutions using a mercury film electrode, Np(IV) solutions in 1M Na_2CO_3 at pH 13 showed no signal with differential pulse anodic stripping voltammetry (DPASV) in the range -1.9V to 0.3V versus Ag/AgCl, as the Np(IV) peak has shifted too far cathodically. This indicates a very large stability constant for the Np(IV) - CO_3^{2-} complex(es).

Studies on $^{242}Pu(IV)$ have begun. Initial work on oxidation of Pu(III) solutions at concentrations up to 1.6 x 10^{-3} M did not produce any electrochemical response, in contrast to work reported elsewhere. Several electrochemical techniques were attempted, but all failed on mercury.

Using a platinum disk electrode, however, Pu(IV) gave excellent electrochemical responses. Differential pulse voltammetry (DPV) from +0.8V to +0.4V gave peaks for the Pu(IV) → Pu(III) reduction in 1M HCl. A linear concentration dependence was also observed, and a detection limit of 1.26 x 10^{-5} M Pu(IV) was obtained.

Using DPASV, oxidation of adsorbed Pu(III) to Pu(IV) on platinum gave good electrochemical signals. The peaks obtained were independent of plating time (an indication of sorption of some reduced species), but linearly dependent on the plutonium concentration in the bulk solution. A detection limit of 3.4 x 10^{-5} M was obtained for Pu(IV).

The detection limit of DPV could possibly be improved through use of a more sensitive current measuring circuit in the potentiostat; the DPASV result is sorption-limited, and is controlled by the size of the electrode. The reduction of Pu(IV) is electrochemically reversible, with $|E_p^c - E_{p/2}^c|$ = 53 mV (theory 55.7 mV), while the oxidation of Pu(III) is quasi-reversible, with $|E_p^a - E_{p/2}^a|$ = 57 mV (theory 55.7 mV).

Work is now proceeding on square wave voltammetry of Pu(IV) solutions, to attempt to verify older work and to improve detection limits. Examination of the Pu(IV) in CO_3^{2-} is also under study over the pH range of 7 to 13, at various electrodes. Reduction of Pu(IV) in 1M CO_3^{2-} gives an electrochemical response on platinum, and a study of the stability constants of such a system will be performed if feasible.

Construction and Testing of Laser Spectroscopy Equipment

Improvements were made in the photoacoustic cells, in order to reduce corrosion and improve cell life. The new cell has been tested and found to work, but is somewhat less sensitive than previous designs. Efforts are now being made to improve the acoustic coupling between the detector and the solution.

Attempts were made to obtain stimulated Raman spectra of benzene and nitrate, both of which are good tests of a system. These attempts used a Chromatix pulsed dye laser, which was unable to provide the laser power needed to observe spectra.

Efforts are under way on obtaining spectra of Nd^{+3} in basic solution, and on a study of Nd^{+3} complexation by OH^- and CO_3^{2-}.

Detailed Study of Actinide Ion-Hydroxide Interactions

Analysis of data collected for the system UO_2^{2+}, OH^-, SO_4^{2-} has been carried out. Data for the hydrolysis of UO_2^{2+} showed that a model using the species $(UO_2)_2(OH)_2^{2+}$ and $(UO_2)_3(OH)_5^+$ fit best in the pH range 3 to 5, for $[UO_2^{+2}] \sim 10^{-3}M$, as indicated in Table 1. (G.O.F. means goodness of fit.)

The stability constants obtained by use of Model 1 were then used in an analysis of UO_2^{2+} - SO_4^{2} data. Results are given in Table 2. In Runs 7 and 8, the best G.O.F. was obtained. Comparison of Runs 7 and 6 shows that no evidence exists for the $(UO_2)(SO_4)_3^{4-}$ species in the pH range 3 to 5 for $[SO_4^{2-}]$ of 0.0132 to 0.0396 M.

FUTURE ACTIVITIES

The above programs will continue, and a new task, Measurements of the Solubilities of Actinide Hydroxides and Complexes--an Automated System, will be set up.

Table 1. Analysis of UO_2^{2+} Hydrolysis Data[(a)].

Model	ℓ_m	ℓ_w	log β	Standard Deviation	G.O.F.
1	2	2	-5.99	0.017	35.37
	3	5	-17.69	0.036	
2	1	1	-6.55	2.66	
	2	2	-5.74	0.095	77.26
	3	5	-17.72	0.088	
3	2	1	-5.50	66.31	
	2	2	-5.95	0.022	43.29
	3	5	-17.72	0.055	
4	2	2	-6.15	0.09	95.11

(a) ℓ_m and ℓ_w are coefficients for the UO_2^{2+} and OH^-, respectively.

Table 2. Analysis of UO_2^{2+} - SO_4^{2-} Complexation.

Run	log K_{110}	log K_{120}	log K_{130}	β_{20-2}	β_{30-5}	G.O.F.
1	1.53	0.78	-	-5.99	-17.7	.50
2	1.75	1.11	-	-6.86	-18.0	.22
3	1.60	0.90	-	-6.18	-18.49	.25
4	1.50	0.90	-	-6.10	-18.0	.33
5	1.60	0.90	0.20	-6.10	-18.0	.36
6	1.60	0.90	0.20	-6.20	-18.5	.24
7	1.60	0.90	-	-6.20	-18.5	.24
8	1.60	0.90	-	-6.30	-18.5	.21

WBS 1.3.2

PROJECT: Waste-Rock Interactions Technology (WRIT) Program

PRINCIPAL INVESTIGATOR: Pacific Northwest Laboratory (R. J. Serne)

ONWI PROJECT MANAGER: J. B. Moody

OBJECTIVE

The objectives of the WRIT program are to:

- Identify and characterize mechanisms of waste form radionuclide release and subsequent geochemical interactions with engineered barriers and natural geologic media, e.g., leaching, solubility, and sorption
- Develop and evaluate the effectiveness of models to predict leaching, sorption, and release processes in the repository and surrounding media
- Obtain, through verification studies and documentation, the most acceptable test methodologies for sorption, leaching, solubility limitations, and waste package-geomedia interaction studies
- Support repository site characterization and licensing.

PROGRESS REPORTED PREVIOUSLY

Changes in column effective porosities with flow rate were found to be reduced with large columns. Experimental K_d values were found to increase as the solution-to-solid ratio increased for batch K_d tests. Adsorption of UO_2^{+2} was modeled empirically by assuming the sorbed species was $UO_2(OH)_2^0$. The effects of ground-water composition on sorption of neptunium and technetium by basalt-related solids were reported. Solubility studies (PNL) of selected actinide compounds were extended to include NpO_2OH(am). The concentration of Np in dilute $CaCl_2$ solutions [Np(V)] contacting NpO_2OH(am) decreased with increasing pH over a pH range of 7 to 12. Further studies were done on methods to control the redox potential in solutions containing multivalent elements. Predicted Eh values from the Fe^{2+}/Fe^{3+} couple agreed with platinum electrode measurements (ORNL) in solutions contacting $Fe(OH)_3$(am). The compound $[Os(bipy)_3]\ (ClO_4)_2\ 2H_2O$ was prepared and tested (LANL) to determine the stability of the complexed Os(II)/Os(III) couple in controlling the redox potential in solution.

Data from a series of minicanister tests were examined. Basalt ground-water concentrations were close to the assemblage albite/analcime/montmorillonite, which may indicate that these phases create a dissolved silica- and pH-controlling mechanism. Also, silica and alkali solution content increased with time, implying that albitization of some bentonite backfill components during the thermal period may be of concern in evaluating backfill components. The degree of preferential sputtering of different elements was investigated. All elements were found to have similar sputter rates except for iron and zinc, which sputtered at a somewhat slower rate. The pH effect on borosilicate waste glass leaching is fundamentally different than on simple silicate glasses. Therefore, modeling efforts based on simple silicate glasses cannot be directly applied to waste glasses.

A list of radionuclides was proposed for setting priorities for experimental work. The literature on leach modeling for glass has been surveyed; most models are based on diffusion in the glass matrix, which appears not to be substantiated as an important process during waste glass leaching. Thermochemical data on nontronite, a common alteration mineral of the Columbia Plateau basalts, were reviewed and evaluated. Estimation techniques were then used to calculate the data needed to add this mineral to the WATEQ (USGS) suite of minerals. In support of the EQ3/EQ6 code (LLNL), the code MCRT was written to aid in the extrapolation of 25 C thermochemical data to higher temperatures. New uranium species were also added to EQ3. A study on natural radionuclide migration was begun to support the salt dome site characterization work.

ACTIVITIES DURING THE REPORTING PERIOD

Fracture flow experiments have begun and are being coordinated with laboratory sorption experiments (determination of surface distribution coefficients, K_a). A comparison of batch, once-through-column, and recirculating column methods for retardation studies was made. The effects of ground-water composition on sorption of cesium, neptunium, and plutonium by basalt-related solids were reported. Experimental uranium concentrations were compared to predictions made with several thermodynamic data bases. Adsorption of Np on kaolinite was studied as a function of both Np concentration and $CaCl_2$ concentration.

A procedure has been developed at PNL to differentiate Pu(IV) from Pu(III) in 10^{-7} to 10^{-6} M Pu solutions using Arsenazo III. This procedure can be applied to the study of Pu compounds of low solubility. Results on the aqueous solubility of Np from doped glass beads indicate that the Np solution concentration is essentially the same as that in solutions contacting $NpO_2(c)$. In addition, quinhydrone was shown to be an effective redox buffer ($E° = 0.7$ V). Additional osmium compounds were synthesized and tested (LANL) for use as redox buffers. The complexed $Os(II)Cl(py)(bipy)_2/Os(III)Cl(py)(bipy)_2$ couple ($E° = 0.48$ V) appears to be stable for at least 10 days. A milestone report (ORNL) on technetium behavior under reduced conditions presented two important conclusions: (1) Tc can be substantially removed from solutions contacting basalt, and (2) the removal mechanism is associated with the reduction of Tc by the redox conditions existing in the suspension.

The PNL/Sandia waste package test components were submitted for surface and solid-state analysis at PNL and Sandia. Several modifications were completed on the autoclave system that will be used for hot-cell testing.

The effect of water radiolysis on elemental leaching from PNL 76-68 glass has been investigated as a function of temperature and of gamma irradiation dose rate. Degassed, deionized water was used as the leachate to prevent nitric acid generation. Radiolysis effects resulted in more accelerated leaching than that found for the unirradiated analogs. Leach rate enhancements were most apparent at low temperatures and decreased in importance with increasing temperature. The temperature range investigated was 50 to 90 C. Enhanced leaching can be attributed to the formation of radiolysis products, since nitric acid formation was prevented. Also, earlier investigations have shown that gamma radiation-induced structural damage, if it occurs, has no discernible effect on glass leaching.

A dose-rate dependence of the leaching rate was found. An increase of 2 orders of magnitude in the dose rate resulted in an approximately 20 percent increase in the silicon leach rate at 70 C. The thickness of the reaction zone on the glasses increased with increasing dose rate, with boron and sodium showing the greatest degree of selective leaching. However, cesium was found to resorb on the surfaces, resulting in a reduced degree of selective leaching.

Leach modeling for waste glasses is being pursued in terms of protective surface layers. A review of geochemical models for the weathering of minerals shows they can be adapted as simple glass leach models. A review of post-test analyses planned for the PNL/Sandia waste package tests shows that surface analyses of the glass surface should contribute to developing realistic glass leach models.

The thermochemical data estimated for nontronite last quarter were coded into the WATEQ data bank. Methods were investigated for estimating thermochemical properties of zeolites important in the ground-water environment. A supporting code for EQ3/EQ6 was rewritten to allow for expansion of the data base, and phosphate and plutonium are now on the primary data file. The process of building the mineral dissolution kinetics capability into the EQ6 code was initiated. The results of the basalt ground-water geochemical modeling study have been evaluated. The ground-water samples compute to be in equilibrium with calcite and a number of amorphic phases ([$Fe(OH)_3$], allophane, and SiO_2). If present in the aquifer, these reactive minerals will play an influential role in limiting or controlling the ground-water composition. In support of the salt dome site characterization studies, the concentrations of ^{226}Ra in six core samples from two domes have been determined. Based on the estimate of uranium concentration from the radium measurements, it will be necessary to chemically separate uranium from the salt in order to determine disequilibrium ratios as a measure of the stability of the domes.

FUTURE ACTIVITIES

Analyses for the PNL/Sandia waste package test will be completed and a status report prepared. Preparation of a leach model of waste glasses will continue; data from the existing literature will be added and the WRIT experimental results incorporated. The minimal dissolution kinetics capability will begin to be built into the EQ6 computer code. The uranium validation of the WATEQ3 geochemical model will be completed, and dating of the salt dome cores will continue.

Experiments to determine PuO_2 and NpO_2 solubilities will be conducted in an anoxic chamber. A series of thermal gradient experiments will be started, using Umtanum basalt and welded tuff along with either 76-68 glass or a simplified glass. Work with neptunium-laden ground water and kaolinite will continue to determine the dominant sorption mechanism.

WBS 1.3.2

PROJECT: Uranium Disequilibrium Dating of Ground Water

PRINCIPAL INVESTIGATOR: Lawrence Berkeley Laboratory (M. Michel)

ONWI PROJECT MANAGER: N. Hubbard

OBJECTIVE

The objective of this study is to further develop the uranium disequilibrium method as a tool for dating ground waters renging from 50,000 to 100,000 years old. This work is primarily directed toward understanding the role of alpha recoil in releasing ^{234}U to the ground water.

ACTIVITIES DURING THE REPORTING PERIOD

Several Hanford region water samples were run. Duplicates of certain analyses are clearly called for in order to begin interpreting the data, but the preliminary results are shown in Table 1, along with two samples previously reported (U-70 and U-71) for completeness.

Modest enrichments have occurred in the presumably shallower waters represented by the springs; however, the geology of the region (a series of basalt sheet flows separated by sediments) would suggest little relationship of surface waters, springs, and deeper layers, other than possible recharge areas somewhat near each other, since the area itself is so dry that it precludes much local recharge. The enrichments in at least some cases are above levels normally seen in shallow aquifers, but not by much. This may indicate that with the reduced uranium concentrations that are evidently common at depth, the same enrichment mechanism could have led to an even greater activity ratio at early stages of the flows. Thus, the existence of at least one modestly deep sample (Ford Well, U-77) with very low uranium concentration and little, if any, enrichment leads to a conclusion of considerable aquifer age. Ages of 250,000 years or larger would be compatible with the data.

The freshly drilled hole, DC2, which was sampled by swabbing, presents a separate problem. It is the only one of this sample series in which doubt exists about sample integrity. The technicians and chemists at the site noted that sampling was done while water still showed some turbidity causing

Table 1. Uranium Disequilibrium Data for Pasco Basin Ground Water.

Sample Number	Designation of Type	Uranium Concentration, parts per trillion	Activity Ratio, ^{234}U/^{238}U
U-70	Bennett Spring	333 ± 7	1.99 ± 0.06
U-71	Drilled hole, DC-6 (flowing freely for >1 year)	9.97 ± 0.08	1.87 ± 0.08
U-72	Drilled hole, DC-2 (sampled by swabbing)	1.21 ± 0.036	1.0 ± 0.1
U-73	Benson Spring	159 ± 8	1.55 ± 0.17
U-74	Rattlesnake Spring	571 ± 9	2.47 ± 0.07
U-76	Juniper Spring	21.7 ± 0.2	2.41 ± 0.07
U-77	Ford Well (artesian since late 1920s)	0.823 ± 0.008	1.0 ± 0.1

them to suspect contamination by drilling mud (and therefore drilling water). Since all samples were filtered, the sample received was clear, but significant material was found on the filter.

Note the extremely low uranium concentration in the sample (U-72, 1.21 ppt), indicating that no gross contamination of drill water (Columbia River water, >114 ppt uranium) is evident, nor could any significant uranium have been leached from the fine clay particles that may have penetrated the filter. Yet tritium analysis of the sample showed levels explainable by perhaps 20 percent contamination by Columbia River water (or other freshwater), which contradicted the observations. The only explanation at this time is that whatever solid was suspended in the water adsorbed almost all the uranium that was naturally present in the water and was removed by the filter. Only a trace of equilibrium uranium was left from some source, such as the small amount of clay or other solids that may have escaped the filter. The other chemical analyses will be reviewed to see if the hypothesis of massive uranium loss seems plausible. Much more interpretation may be possible from other geochemical data.

WBS 1.3.2

PROJECT: Helium Dating of Ground Water

PRINCIPAL INVESTIGATOR: Savannah River Laboratory (SRL) (I. W. Marine)

ONWI PROJECT MANAGER: N. Hubbard

OBJECTIVE

The age of ground water is of great importance when selecting a site for a geologic repository for radioactive waste. Many methods of radioisotopic dating of ground water depend on some assumed initial concentration of a radioactive element in the atmosphere. Depending on the half-life of the specific isotope, there is a finite time period in which the isotope will decay to an undetectable concentration. At that point, a minimum age of the ground water is defined, although the true age may be considerably older.

However, an isotopic dating technique using the accumulated decay products that originate in the ground rather than in the atmosphere is not limited by the age of nondetectability, since the older the water, the greater the concentration of the stable daughter products. The studies at SRL are aimed at developing methods for dating ground water from the accumulation of these stable daughter products. Samples from several wells which are in proximity will be dated using helium accumulation methods. These samples should give similar age dates because of the proximity of the wells. If there is substantial variation, the method will need to be reevaluated.

ACTIVITIES DURING THE REPORTING PERIOD

The basic design of the equipment used to collect helium for dating ground water has been changed, and resampling of four wells is under way. The original design called for collecting a gas sample, which had effervesced at atmospheric pressure, and calculating the total gas present in the water. As a check on this calculation, a "depleted" water sample was also collected. It was difficult to guarantee exactly 1 atmosphere pressure at effervescence in the moving water system.

The new design calls for collecting only a water sample, without a companion gas sample, at a pressure above that of effervescence. This pressure is estimated to be less than 2 atmospheres.

WBS 1.3.2

PROJECT: Chlorine Dating Studies

PRINCIPAL INVESTIGATOR: University of Arizona (S. N. Davis)

ONWI PROJECT MANAGER: N. Hubbard

OBJECTIVE

The objective of this research is to evaluate the ^{36}Cl ground-water dating method. This evaluation requires constructing and testing a ^{36}Cl ground-water dating theory; developing ^{36}Cl sampling and analysis techniques; determining the environmental behavior of ^{36}Cl by comparing it with that of halides and other solutes; investigating possible ^{36}Cl sources and sinks; and comparing, where possible, this method with other ground-water dating methods.

A successful ^{36}Cl dating method will provide experimental data to calibrate numerical hydrogeologic models describing the movement of waters and solutes in the vicinity of proposed high-level nuclear waste repositories. Such movement is the most probable mechanism for transport of nuclear wastes to the biosphere.

PROGRESS REPORTED PREVIOUSLY

The ^{36}Cl ground-water dating project was initiated 1 October, 1980. The following activities took place previously:

1. Theoretical predictions were made of expected ^{36}Cl concentrations based on geographical and geochemical parameters.
2. A total of 189 samples for ^{36}Cl and closely related analyses have been collected; 118 of those collected have been processed chemically, and 38 have been counted for ^{36}Cl.
3. Profiles of ^{36}Cl concentrations were obtained for the Fox Hills-Basal Hell Creek, North Dakota, and the Carrizo Sand, Southeast Texas.
4. Hydrodynamic and hydrochemical models were being developed to aid in the interpretation of ^{36}Cl data.
5. Preliminary interpretations were made of the significance of the counted samples.
6. Progress reports were presented to the Nuclear Structure Research Laboratory (University of Rochester), the American Geophysical Union, and the American Chemical Society.

ACTIVITIES DURING THE REPORTING PERIOD

A ^{36}Cl standard, traceable to the NBS standard, was prepared as $^{36}\mathrm{Cl}/\mathrm{Cl} = 10{,}000 \pm 200$ and was counted. The ^{36}S content of the samples determines counting background. Time-resolved flame emission spectroscopy was used to determine sulfur content, but no correlation was found with the ^{36}S level observed previously. Sample holders are now thought to be the principal contributors to sulfur background. Sulfur is now expected to be much less of a problem due to recent LaB_6 source development and to the high-pressure liquid chromatograph (HPLC) cleanup procedures.

Input of ^{36}Cl is predicted to vary by location; two important parameters seem to be latitude and distance from the ocean. Figure 1 predicts ^{36}Cl/Cl ratios at various locations within the United States.

The two aquifers for which there are sufficient, although limited, data to establish a ^{36}Cl concentration profile show ^{36}Cl interpreted as constant input modified by downgradient leakage. If these interpretations are correct, ion filtration is important in both these regional aquifers. The use of ^{36}Cl to provide significant information about ion filtration, its magnitude, and how it affects migration of other solutes in the subsurface is suggested by these data. The preliminary interpretation of the Milk River aquifer, southern Alberta, from which more than 40 samples for ^{36}Cl and $^{35}Cl/^{37}Cl$ analyses have been obtained, suggests that it will be possible to use the chloride isotope data to distinguish between the concentration mechanisms of ion filtration, megadispersion, and diffusive transport. Each much be considered when one models the transport of radionuclides.

The Great Australian Artesian Basin, Australia, appears to be free from the leakage-induced geochemical complications of the other systems being studied. This regional aquifer also offers flow paths sufficiently long that the prospect of calibrating ^{36}Cl dating over its entire 1,000,000-year useful dating range seem excellent. No other aquifer that has been investigated is as suitable. A cooperative venture has been arranged with Australian scientists for a thorough investigation of the Great Artesian Basin by isotopic and chemical methods.

As part of the investigation of ion filtration, changes in $^{35}Cl/^{37}Cl$ ground-water ratios are being determined. A theory has been developed indicating that ^{35}Cl will be concentrated more efficiently than ^{37}Cl. An analytical procedure for preparing the chloride isotope sample has been selected: A silver chloride precipitate is reacted with methyl iodide, producing methyl chloride which, after vacuum line separation and purification, will be counted in a modified micro-mass ratio mass spectrometer.

An important limitation to ^{36}Cl ground-water dating, but which is potentially useful in evaluating the presence of, or even the rate of salt deposit dissolution, is the subsurface neutron activation of ^{35}Cl. Uranium-rich samples have been obtained from several sites; their mineral chloride will be analyzed for ^{36}Cl and compared with expected values that can be calculated. Samples of salt domes, bedded salts, and associated brines will also be collected for analysis.

Contamination of the samples, either by natural mixing processes or by sample handling procedures, is an important parameter. High levels of contamination have been observed in the youngest water samples. The ^{36}Cl of nuclear weapons-testing origin is expected to be much higher than natural levels. The bomb-origin pulse has been theoretically constructed from published data via a box model. Its peak is predicted to be in 1955, at a level 4 orders of magnitude higher than natural background. Current fallout is predicted to be negligible. Rainwater ^{36}Cl is being collected to test the model prediction.

An ancillary technique for ground-water dating, ^{129}I, is also being tested, primarily because the Tandem accelerator in Rochester can analyze for it at very low levels. The Madison Limestone, Wyoming, ground water is calculated to double its $^{129}I/I$ ratio in 25,000 years. Also, ^{129}I may show the extent of hydraulic contact between salt dome fluids and those in outside formation waters. Laboratory techniques for ^{129}I separation from natural water have been worked out by using a bisulfite-loaded anion exchange resin, and field collection techniques are being started. Optimization of iodine collection from the necessary large water volumes is being tested.

FUTURE ACTIVITIES

Because AgCl precipitation from dilute or iron-containing water is a difficult and inefficient procedure, anion-exchange chloride separation procedures will be instituted. HPLC ion exchange will be used to separate sulfur and to produce an alkali metal salt sample that will adsorb much less sulfur. A temporary $^{35}Cl/^{37}Cl$ preparation line will be constructed. Rainwater will be collected from the Tucson summer storms. Sample transects will be made using the map in Figure 1 for guidance. Brines for evaluation of steady state background ^{36}Cl will be collected from New Mexico and Texas; ^{129}I will be collected from WIPP, New Mexico, Texas, and salt domes in Louisiana.

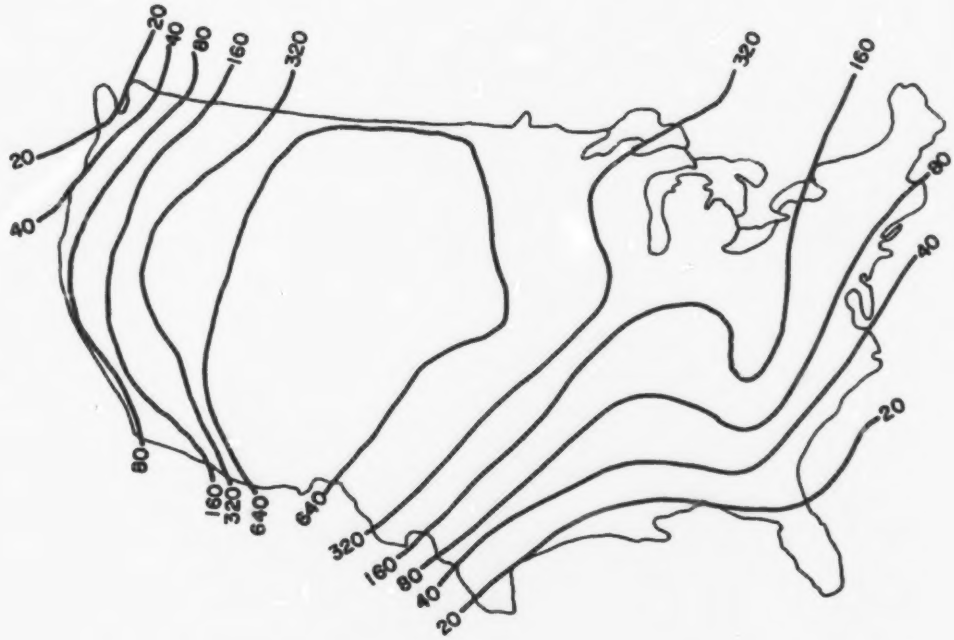
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Figure 1. Calculated $\frac{^{36}Cl \times 10^{15}}{Cl}$ Ratios in U.S. Ground Water Before Nuclear Weapons Testing Took Place.

WBS 1.3.2

PROJECT: Osmotic Effects of Clay

PRINCIPAL INVESTIGATOR: Savannah River Laboratory (I. W. Marine)

ONWI PROJECT MANAGER: N. Hubbard

OBJECTIVE

The objective is to determine the effects of natural osmotic membranes on natural hydraulic gradients in argillaceous formations.

ACTIVITIES DURING THE REPORTING PERIOD

The paper, "Osmotic Model to Explain Anomalous Hydraulic Heads", was published in the February 1981 issue of Water Resources Research. Laboratory experiments have shown that compacted clays act as osmotic membranes when they separate aqueous solutions of unequal ionic concentration. Theoretically, osmotically induced differential hydraulic pressure in ground-water systems can be relatively high. The magnitude depends primarily upon concentration differences across the membrane, type of ions, type of clay, and pore size. In experiments, thin, compacted clay membranes commonly exhibit varying degrees of osmotic efficiency due to ion leakage through the clay. In natural systems, the membrane and the solution containers are not as distinct and well defined as they are in the laboratory. Moreover, the membrane is commonly thick, inhomogeneous, and composite. In a buried Triassic basin at the Savannah River Plant near Aiken, South Carolina, it is suspected that osmosis causes the saline water in the basin center to be slightly geopressurized in relation to fresh water in the overlying coastal plain aquifer. Two wells have heads of 7.88 and 12.98 bars (114.3 and 118.3 psi) above the head in the coastal plain aquifer. The head in each of these wells approximates the osmotic equilibrium head calculated from solution concentration of water produced by each well (12,000 and 18,500 mg/l, respectively). Other wells penetrating the top and edge of the Triassic basin probably penetrate a zone where ion leakage gives rise to less saline water. Thus, these wells are not geopressurized.

A hyperfiltration test on montmorillonite is in progress. Hydraulic conductivity of the sample has been measured. Fluid of known salinity is now being forced through the sample under pressure, and the salinity of both the filtrate and the reject solution is being determined. The experiment is slow as only 29 cc/day is forced through the membrane. However, from this experiment it appears that both the osmotic efficiency and back diffusion of salt can be measured.

WBS 1.3.2

PROJECT: Effects of Organics in Deep Ground Water

PRINCIPAL INVESTIGATOR: Battelle Columbus Laboratories (J. L. Means)

ONWI PROJECT MANAGER: J. B. Moody

OBJECTIVE

The objective of this program is to fully evaluate the possibility that organic complexing agents from a variety of sources, including the ground water, the repository rock, or the waste itself, may form strong complexes with certain radionuclides and significantly increase radionuclide transport rates from the repository. This research will have an important impact on the safety analysis of the repository and also on site selection.

PROGRESS REPORTED PREVIOUSLY

This program was initiated in February, 1979. Major findings since then include the following: (1) ethylenediaminetetraacetic acid (EDTA) was identified in eight different ^{238}Pu-contaminated trench leachates from the Maxey Flats radioactive waste burial grounds in Kentucky; (2) the effect of humic and fulvic acids, carbonate, and bicarbonate on U_3O_8 dissolution rates has been experimentally measured; (3) a number of organic acids and phenols have been detected in groundwater samples from Hanford, Washington, and the Finnsjön and Sternö areas of Sweden; (4) mineral and water radionuclide partitioning analyses have been conducted to determine the effect of temperature (25 to 200 C) and oxalic acid content on the adsorption of cobalt, strontium, cesium, and uranium onto kaolinite. Results to date show that systems containing oxalic acid exhibited even greater metal adsorption by kaolinite than systems lacking oxalic acid. Also of interest is that the Kd for strontium and cobalt with kaolinite actually increased with increasing temperature from 100 to 200 C at pH 5 to 6 under mildly reducing conditions.

ACTIVITIES DURING THE REPORTING PERIOD

Research in this program is being conducted in three separate tasks: (1) a laboratory analysis of actinide-humate complex characteristics, including the strength and colloid characteristics of such complexes; (2) mineral and water radionuclide partitioning experiments to evaluate the effects of organic ligands on radionuclide migration rates as a function of temperature, pH, and oxidation-reduction potential; and (3) six additional groundwater samples from Sweden are being analyzed by gas chromatographic-mass spectrometric (GC-MS) procedures for ligands, and humic substances in these samples are being isolated, purified, and chemically characterized.

Actinide-Humate Complex Characteristics

In some 200 separate experiments conducted to date, the colloid characteristics of complexes of humic acid (HA) and fulvic acid (FA) with uranium, thorium, americium, plutonium, neptunium, sodium, calcium, aluminum, Fe^{2+}, and Fe^{3+} at pH 3.5 to 9.0 have been evaluated. The experiments consist of adding a known amount of soluble metal salt (usually either the nitrate or chloride salt) to a given concentration of purified HA or FA dissolved in water. Three reaction units containing identical metal and organic acid contents are then pH-adjusted, using either HCl or NaOH, to pH 3.5, 6.0, or 8.5. In certain reaction units, a dark-brown flocculant is formed during the first several hours of standing. The solutions are agitated for 24 hours and then filtered through a 0.22 μm membrane. Dissolved organic carbon and metal contents of the filtrates are measured to determine the extent of HA or FA and metal flocculation.

Selected results from experiments conducted this past quarter show that uranium and thorium form insoluble complexes with HA and FA in the pH range of 7 and below. Lower pH and higher U and Th concentrations promote formation of insoluble complexes. With neptunium, americium, and plutonium, insoluble complexes were formed at pH 3.9 and to a lesser extent at pH 6.0. However with Np and Pu, the amount of dissolved actinide-humate complex formed exceeded the inorganic solubility of the two actinides at a given pH. Therefore, even though some insoluble complex was formed, humic and fulvic acids served to greatly increase the amount of Np and Pu in solution as compared to solutions of Np and Pu lacking humic and fulvic acids.

These experiments are being continued. The flocculation of HA and FA by other metals such as Al, Fe^{2+}, and Fe^{3+} has been examined, and the results are currently being tabulated. Also, many experiments using lower HA and FA starting concentrations have been conducted, and the results will be reported.

Radionuclide Partitioning Experiments

Princeton University continues its studies on the adsorption of strontium, cesium, cobalt, and uranium by different minerals in the presence of organic acids from 25 to 200 C. In addition, an analysis of the thermal breakdown of organic acids as a function of temperature has been initiated.

Organic Geochemistry of Deep Ground Water

A draft report on the organic geochemistry of deep ground water was revised. Results of the dialysis and gel filtration chromatography (GFC) separation procedures for five different ground-water samples are presented in Table 1. The ground waters from Finnsjön, Sweden, contain about 6 percent humic acid, 2 to 3 percent >1,000 molecular weight (MW) fulvic acid, but the majority of the dissolved organic species present are <1,000 MW species. The sample from the Stripa Mine in Sweden contains no humic acid. Only 2 percent of the total organics present are >1,000 MW species, and 98 percent are <1,000 MW. The ground water from Hanford is slightly different, in that 10 percent of the organic matter is >1,000 MW and 90 percent is <1,000 MW. In conclusion, the majority of the dissolved organic matter in all five of the ground waters is low molecular weight fulvic acid or compounds resembling low molecular weight fulvic acid.

Table 1. Results of Humic Acid Separation, Dialysis, and GFC Fractionation Procedures on Five Selected Ground-Water Samples, by Percent.

Sample	HA	>1,000 MW	700-1,000 MW	300-700 MW	<300 MW
Finnsjön #4 260 m	6	2	8	19	55
Finnsjön #4 382 m	6	2	6	13	73
Finnsjön #4 562 m	6	3		91	
Stripa Mine	0	2	10	45	43
Grande Ronde, DC-6	0	10	53	34	3

WBS 1.3.3

PROJECT: Geologic Project Manager Program--Salina Basin

PRINCIPAL INVESTIGATOR: Stone & Webster Engineering Corporation (D. S. Pierce)

ONWI PROJECT MANAGER: R. R. Nicks

OBJECTIVE

The objective of the GPM program for the Salina Basin is to plan and manage a systematic investigation of the geologic and hydrologic characteristics of the bedded salt deposits and their enclosing rocks within the basin. This investigation will provide fundamental information necessary to evaluate the basin as a whole, and areas within it, for nuclear waste repository siting.

PROGRESS REPORTED PREVIOUSLY

The program began on 21 July, 1977. A regional geological characterization was undertaken of those portions of the Michigan and Appalachian Basins underlying Michigan, Ohio, and New York. The regional study consisted entirely of a survey of the available technical literature. It was supplemented in New York and Ohio with an extensive compilation of the stratigraphy from an examination of geophysical logs from hundreds of oil and gas wells. A computer program was developed and applied to central New York for modeling multidensity ground-water flow. The principal result of these studies was the identification of areas in New York and Ohio that appear to comply with site-qualification criteria. A program was prepared outlining necessary further investigations.

ACTIVITIES DURING THE REPORTING PERIOD

A preliminary assessment continued of whether, and under what conditions, fractured salt heals naturally. A draft report was submitted for ONWI review, and comments have been received. As the comments were being resolved, several important additional references were discovered that altered the body and conclusions of the report. Recent laboratory studies have demonstrated that salt fractures can heal under conditions that exist in nature and within the anticipated depth range of a repository.

WBS 1.3.3

PROJECT: Paradox Basin Geologic Exploration

PRINCIPAL INVESTIGATOR: Woodward-Clyde Consultants (WCC) (F. R. Conwell)

ONWI PROJECT MANAGER: N. A. Frazier

OBJECTIVE

The objective is to plan and conduct geologic work required to identify, investigate, characterize, and license a repository in salt.

PROGRESS REPORTED PREVIOUSLY

This project began on 30 August, 1977, and includes drilling support to USGS, a vertical seismic profiling (VSP) program, and geologic siting investigations. The USGS drilling program has been completed; site restoration is ongoing. The VSP program is in its second phase and nearing completion. The first phase of the siting investigation has been completed.

The second phase, now under way, involves area-level siting investigations in four study areas: Elk Ridge, Gibson Dome, Salt Valley, and Lisbon Valley. Studies reported previously have included geologic mapping; seismic monitoring; aerial and ground reconnaissances and evaluations of structure, physiography, topography, Quaternary deposits, and geomorphology; hydrogeologic and geotechnical testing; and a borehole drilled in the Gibson Dome study area.

ACTIVITIES DURING THE REPORTING PERIOD

The primary field activity was the reentry of the Kubat borehole (Section 23, T37S, R19E) in San Juan County, Utah. The reentry program calls for cleaning the existing hole and coring the plugs; deepening the hole to the base of the Leadville limestone (approximately 4,000 feet); obtaining geophysical logs and sidewall cores; and performing hydrogeologic testing. During this quarter, necessary permits and approvals were obtained, procedures and test plans were prepared, and necessary equipment and services were procured. At the end of the quarter, drilling operations were ongoing at approximately 3,000 feet.

Other drilling-related activities included preparatory activity (procurement and procedures) for the planned long-term hydrogeologic testing at the Gibson Dome No. 1 borehole and Elk Ridge No. 1 borehole.

The geomorphology and Quaternary history activity was involved in monitoring laboratory analyses of soil samples collected in and around the study areas. Preliminary laboratory test results regarding pretreatment of soil samples prior to particle size analysis indicated the need to remove calcium carbonate from the samples. Removal of silica, organic material, manganese, and iron oxide did not significantly affect the particle size distribution derived from hydrometer analysis. The laboratory proceeded with particle size analysis and measurement of carbonate content for the remaining samples.

Within the hydrogeology activity, geochemical analysis of water samples from the Leadville limestone continued. A computer program was developed for the geochemical data base that generates scattergrams for various ionic concentrations. Another computer program to calculate redox potential (reduction-oxidation) and mineral equilibria for a given water sample was ordered, and a key data entry program was written to accommodate data obtained from Kubat in the Hewlett-Packard computer data analysis system.

To aid in the determination of the redox potential of water samples, ferrous iron (Fe^{2+}) will now be measured in the field immediately upon collection of the water samples. The speciation of iron between its ferrous (Fe^{2+}) and ferric (Fe^{3+}) forms is indicative of the water's reducing

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potential. The ferric iron concentration will be calculated by subtracting the ferrous iron concentration, determined in the field, from the total dissolved iron concentration measured in a laboratory. Reagents for the colorimetric method of Fe^{2+} determination were ordered, and changes to the appropriate technical procedures were made.

A drilling fluid tracer program was started for the Kubat reentry program. A tritium-dead water was obtained for analysis in order to evaluate laboratory performance. A new field analytical procedure was developed for thiocyanate tracer determination in the alkaline, cross-linked polymer mud system used in the Kubat borehole.

The seismology activity continued routine operation of the long-term microseismic network. Mining- and river-induced seismicity studies also continued. The structural geology group began interpreting these seismic reflection data.

All project groups prepared first drafts of the Area Chracterization Report, which presents the geologic setting of the Elk Ridge, Gibson Dome, and Lisbon Valley study areas.

FUTURE ACTIVITIES

Future planned activities include completion of the Area Characterization Report and drilling at Elk Ridge No. 1.

WBS 1.3.3

PROJECT: Paradox Basin Studies

PRINCIPAL INVESTIGATOR: U.S. Geological Survey, Denver, Colorado (R. J. Hite, Coordinator)

ONWI PROJECT MANAGER: N. A. Frazier

TASK 1: GEOLOGY
(R. J. Hite)

OBJECTIVE

The objective is to conduct geological studies in the Paradox Basin to determine which one, if any, of the many salt-core anticlines in the basin should be investigated as a potential site for a repository.

PROGRESS REPORTED PREVIOUSLY

The project began in 1978 under the Office of Waste Isolation (OWI-Union Carbide). Cuttings from Salt Valley drillholes DOE No. 1 and No. 2 were analyzed for bromine by X-ray fluorescence. Plots of these data show that both holes penetrated the same halite bed which is overturned and nearly vertical. A method developed that determines the water content of halite rock involves dissolving the halite sample in methanol and then determining the amount of water in the methanol using a Karl Fischer titrator.

A method is being developed to determine the chemical composition of the brine inclusions in halite rocks. The distribution of trace bromine in halite from DOE No. 3 indicates this hole penetrated the same bed found in DOE No. 1 and No. 2 and that it is also overturned at this location. The determinations of water-insoluble material in the halite rock of DOE No. 3 show that it is very low, averaging about 1.5 weight percent. X-ray diffraction (XRD) examinations of these residues show that they generally consist of about 95 percent anhydrite, with the remainder made up of quartz, dolomite, calcite, and trace amounts of illite.

A longitudinal section through the Salt Valley anticline shows that the caprock overlying the salt is sealed off to the northwest by a thick cover of Mancos shale. Additional geologic barriers to hydrologic flow paths from the caprock are the deep and structurally closed synclines flanking the structure. Pyrolysis fluorescence (PF) of the Salt Valley samples shows that only very small amounts of hydrocarbons are generated by additional thermal maturation. Clay mineralogy for Salt Valley shows the clays have low-exchange capacity and no structural water.

ACTIVITIES DURING THE REPORTING PERIOD

The Salt Valley volume of the Paradox Basin area characterization draft was prepared. Progress was made during the quarter on characterizing the cores from Gibson Dome, including (1) sampling of all halite beds from Salt 4 to 15; (2) analyses by XRD on whole rock samples and insoluble residues for Salt 4, 5, 6, 7, 8, 9, 10, and 13; and (3) determination of bromine values on 2-foot sample intervals through Salt 6, mineralogy of the marker bed above and below Salt 6, and pyrolysis fluorescence on samples from the marker beds above and below Salt 6. In addition, cores from the potash-bearing intervals in Salt 13 and 18 were quartered and submitted for chemical analyses.

Halite samples from the Asse Mine in West Germany will be analyzed for water content using the methanol extraction technique. The samples have been received and prepared for this determination. Because of the highly fractured nature of some of these samples, a technique of dye impregnation was developed which makes microfracturing, induced by the coring process, highly visible. This technique is very useful for selecting core samples for water content determination. Samples which are highly fractured will have lost much of their inclusion water.

Some of the preliminary work on Salt 6 (the potential depository layer) can be summarized as follows:

1. The carnallite marker, which is regional in extent, is well developed in the Gibson Dome core. It is about 130 feet thick and occupies the upper half of the salt bed. It consists primarily of halite rock that contains carnallite ($KCl \cdot MgCl_3 \cdot 6H_2O$) and kieserite ($MgSO_4 \cdot H_2O$). The maximum amount of carnallite present in any of the 2-foot sample intervals does not exceed 20 percent and thus does not constitute a potash resource. Regional correlations show that the carnallite marker cuts across stratigraphic boundaries.
2. Water insoluble residues for Salt 6 average about 4 weight percent. This material consists primarily of anhydrite, with minor amounts of quartz, talc, chlorite, dolomite, calcite, and kieserite. Plots of the vertical distribution of weight percent insolubles, in Salt 6 in Gibson Dome (GD) No. 1 and in a corehole located about 20 miles north at Shafer Dome, show good correlation. From these correlations it can be shown that regional thinning (Salt 6 is 310 feet thick at Shafer Dome) is accomplished principally by internal thinning. There appears to be no loss of halite at the top of Salt 6 in Gibson Dome No. 1 due to dissolution.
3. The plot of vertical distribution of bromine in Salt 6 halite in Gibson Dome No. 1 shows a normal profile. At the base of the bed bromine values are about 80 ppm, but rapidly increase to about 220 ppm at the base of the carnallite marker and remain in this range to the top of the bed. No diagenesis (solution and recrystallization) is indicated by this profile.

FUTURE ACTIVITIES

The following activities are planned:

1. Chemical analyses of the potash deposits in Salt 13 and 18 at Gibson Dome.
2. Clay mineralogy of insoluble residues in Salt 6 and the confining marker beds at Gibson Dome.
3. Determination of the H_2O content of halite rock in Salt 6 at Gibson Dome.
4. Analyses of occluded gases in halite rock at Gibson Dome.
5. Preparation of the Salt Valley volume for the area characterization draft.

TASK 2: HYDROLOGY

(M. S. Whitfield)

OBJECTIVE

The project has two goals: (1) reconnaissance definition of the hydrology of the Paradox Basin in Colorado and Utah, and (2) definition of the hydrology of a site in Salt Valley, Utah.

PROGRESS REPORTED PREVIOUSLY

The Paradox Basin hydrologic project began in November, 1977. In the previous quarter, project reports were in various stages of completion and review.

ACTIVITIES DURING THE REPORTING PERIOD

The reconnaissance reports on the Green River-Moab area, hydrology for the Moab-Monticello area, well-testing for wells DOE Nos. 4 through 9, hydrology for the Blanding-Durango area, hydrology of the Dolores River area, and the San Miguel area are in various stages of review and revision.

FUTURE ACTIVITIES

During the next quarter, the reconnaissance reports on the Green River-Moab area and the hydrology of the Moab-Monticello area will be revised. Colleague review for the Blanding-Durango and San Miguel River Basin reconnaissance reports will be completed. The Dolores River Basin reconnaissance draft will be completed.

TASK 3: ELECTRICAL AND ELECTROMAGNETIC SURVEYS
(R. D. Watts)

OBJECTIVE

The objectives are (1) to investigate specific sites in the Paradox Basin (Salt Valley, Gibson Dome, Elk Ridge) for possible structural, material, or hydrologic difficulties for long-term waste disposal, and (2) to evaluate the effectiveness of various geophysical methods for studying structure and hydrology in the Paradox environment and for locating geologic inhomogeneities beyond the range of conventional well-logging probes.

PROGRESS REPORTED PREVIOUSLY

These conclusions were drawn from the electromagnetic studies at Salt Valley: (1) slingram, a ground-based moderate penetration method, detected anomalies due to near-surface perched water pods; (2) extremely low-frequency (ELF) loop-loop soundings indicated no continuous areas of dissolution above or below the salt; (3) DC resistivity soundings were of limited use as DC currents did not penetrate below the resistive salt and there was no evidence of present-day dissolution at the top of the salt; (4) a helicopter-borne electromagnetic (EM) survey detected linear anomalies within Salt Valley that may be either lithologic or hydrologic variations (anomalies on the flanks of the anticline appear to be expressions of splay fault or zones of extensive jointing); and (5) geophysical well logs were successfully interpreted to give positive identification of most rock types in the evaporite sequence.

These conclusions were drawn from the Gibson Dome-Lockhart Basin studies: (1) hole-to-surface resistivity measurements were successfully made from 3 source depths in drillhole GD No. 1; (2) VLF (very low-frequency, 15 to 20 kHz) magnetic field tilt and ellipticity measurements, used to map continuations of the geologically mapped main Lockhart fault system onto an area covered by eolian deposits, detected parallel faults in the center of and to the north of Shay Graben and found that the circular features on top of Hatch Point are not structural in nature; (3) dipole-dipole resistivity surveys in the vicinity of GD No. 1 revealed remarkable uniformity of rock conductivity except for the east end of the Gibson Dome; and (4) magnetometric resistivity (MMR) measurements appear to be as effective as VLF in mapping faults, and the penetration of the method is greater than that of VLF.

ACTIVITIES DURING THE REPORTING PERIOD

The interpretation of the hole-to-surface resistivity data for GD No. 1 has been completed. The conductive fluid in the drillhole made it impossible to obtain a quantitative estimate of the bodies causing the resistivity anomalies. However, the final results do show that the area around hole GD No. 1 is not a simple layered geometry, but contains many anomalies in the geoelectric section.

In the Gibson Dome-Elk Ridge area, 43 vertical electrical soundings (Schlumberger soundings) were obtained. The survey area is bounded on the west by Canyonlands National Park and the Colorado River, on the east by Kane Springs Canyon, and on the south by the Abajo Mountains. Preliminary processing has been done on the data to obtain true earth resistivity from the measured apparent resistivities, assuming a layered-earth model. Maps of resistivity are being prepared at various elevations within the geologic column in order to locate anomalies and map electrical structures.

Report preparation is proceeding for earlier electromagnetic survey results, as well as for the recently obtained DC resistivity results.

FUTURE ACTIVITIES

The draft of the interpretation of GD No. 1 hole-to-surface results will be completed.

TASK 4: SEISMIC PROFILING

(A. H. Balch)

OBJECTIVE

The objectives are (1) to evaluate the state of the art of downhole seismic equipment for profile mapping of interbeds in salt; (2) to use seismic geophysical data to characterize and differentiate subsurface lithologies and structural configurations in areas of interest; (3) to obtain a surface seismic profile at the Elk Ridge area which will be tied into the DOE Elk Ridge test well; and (4) to map the Paradox salt in this area, especially for thinning, solution cavities, and faulting, and also the subadjacent strata, including basement in the vicinity of Comb Ridge.

ACTIVITIES DURING THE REPORTING PERIOD

No progress report was submitted for the period.

TASK 5: REMOTE SENSING

(J. D. Friedman)

OBJECTIVE

The objective of the Paradox Basin remote sensing project is to acquire, process, and interpret geologically a variety of satellite and aircraft image products of the region in order to assess factors in the tectonic and geomorphologic environment that might significantly affect the quality of a nuclear waste repository site. Particular attention will be given to detecting and delineating previously unmapped structures.

ACTIVITIES DURING THE REPORTING PERIOD

No progress report was submitted for the period.

WBS 1.3.3

PROJECT: Permian Basin Geologic Studies

PRINCIPAL INVESTIGATOR: Texas Bureau of Economic Geology (TBEG) (T. C. Gustavson)

ONWI PROJECT MANAGER: G. D. Brunton

OBJECTIVE

The objective of this project, since its inception in mid-1977, has been to characterize the geology and hydrology of the Palo Duro and Dalhart Basins of the Texas Panhandle. Bedded Permian salts within these basins are being studied to determine if they may contain sites suitable for a repository for high-level nuclear waste.

PROGRESS REPORTED PREVIOUSLY

The third year of analysis was highlighted by initiation of a regional basement structural analysis, quantification of geophysical log parameters, analyses of the water content of basin salts, continuation of the petroleum source-rock analysis, hydrogeologic mapping, characterization of cores, genetic stratigraphic facies mapping, climatic-geomorphic monitoring of the Texas Panhandle, and continued investigations of the processes, timing, and rates of salt dissolution. Each study provides a basis for detailed data interpretation and future integration of research elements. Activity in the previous quarter included completion of four topical reports on salt dissolution and one report on the water content of salt.

ACTIVITIES DURING THE REPORTING PERIOD

Remote Sensing, Shallow Stratigraphy, and Surficial Analysis

A total of 15 regional stratigraphic cross sections of Upper Permian, Triassic, and Tertiary strata in the Palo Duro Basin have been completed. The cross sections illustrate basin structure, regional salt stratigraphy, and collapse structures over zones of salt dissolution.

Analysis of the structural controls on stream development have been completed for the areas of the Pecos Plains, the Canadian Breaks, and the Southern High Plains Surface, and the subsurface data suggest that the positions of both the Pecos and Canadian Rivers are controlled by regional salt dissolution and that as much as 400 ft of the deep valleys occupied by these streams has resulted from subsidence.

Hydrology and Geochemistry

A cooperative program with the U.S. Corps of Engineers was recently completed. The program included drilling and producing a series of shallow wells in the salt dissolution zone in the eastern part of the Palo Duro Basin. Lithologic descriptions of core material and geophysical logs have been made available to TBEG. Water samples from these wells are now undergoing chemical and isotopic analysis.

The preliminary study of clay minerals in the Palo Duro Basin (Permian strata) has been completed.

Basin Analysis

Mobeetie Field, which produces oil and gas from granite wash, is being studied as a model for possible hydrocarbon production in the Palo Duro Basin. The principal trapping mechanism at Mobeetie Field is structural draping of Pennsylvanian beds over a horst block, forming a doubly plunging anticline. However, within the area of closure there is stratigraphic control of reservoir quality and production. Updip fluvial sandstones and undisturbed distal fan-delta deposits exhibit good porosity and permeability and produce oil. Reworked fan-delta deposits are not productive, even within the area of closure, because of loss of porosity by calcite cementation.

Because authigenic minerals play such an important role in determining reservoir quality in Mobeetie Field, the distribution of cements was studied in detail. Point counting across an evenly spaced grid of 200 points was done on 90 granite wash samples. Mineralogy, porosity, grain size, and cement types were identified. Locations of different cements were plotted on cross sections to show three-dimensional distribution of the various types of authigenic minerals. Calcite cement appears to be the most important control on reservoir quality within the field. Chlorite and quartz cements are more common in undisturbed braided-channel deposits.

Host Rock Analysis

The study of the Swisher and Randall Counties core was continued, and outcrop work on the Upper Permian Quartermaster Formation was initiated.

Work on the Swisher County core included a petrographic study of the salt-bearing Lower and Upper San Andres Formation and a physical description of the Triassic and Pliocene sections. Work on the Randall County core involved a physical description of Triassic and Pliocene strata. The objectives of these studies are to determine the properties of potential host rock, the depositional and diagenetic histories of potential host rock, and the economic potential of all rock contained in the core.

The lower part of the San Andres Formation consists of cyclical deposits of siliciclastic mudstone, carbonate, anhydrite, and halite rocks. Carbonate rocks predominate in the lower third and evaporites in the upper two-thirds. The upper part of the San Andres Formation is an evaporite-rich sequence consisting largely of halite and anhydrite. Siliciclastics and dolomite constitute a minor amount of the sequence. The San Andres accumulated in shallow shelf and sabkha environments; cementation of porous sediment by halite occurred shortly after deposition; subsequent diagenetic events have been minor.

The Triassic Dockum Group comprises a terrigenous clastic suite of conglomerate, sandstone, siltstone, and minor mudstone. The Dockum accumulated in a continental basin which received sediment from multiple source rocks that surrounded the basin. A variety of fluvial and delta systems contributed coarse sediment to the lake margin. Lake deposits consist mostly of red, burrowed siltstone and mudstone, indicating shallow oxidizing conditions.

The Pliocene Ogallala Formation is made up, for the most part, of terrigenous clastics and a minor amount of fresh-water limestone. Conglomerates and sandstone are the dominant rock types; siltstone and mudstone are minor. The Ogallala has undergone extensive alteration through calichification. The Ogallala represents a part of a huge wet alluvial fan system on which small lakes were developed.

Seismicity and Tectonic Environment

A two-dimensional gravity model for the Palo Duro Basin has been completed. The basement structure of the Palo Duro and Dalhart Basins has been completed.

FUTURE ACTIVITIES

Reports will be completed on erosion monitoring, morphometric analysis, hydrologic modeling of the salt dissolution zone, whole rock chemistry, hydrocarbon resources of the granite wash, and the petrology and petrography of core material from the Randall and Swisher County stratigraphic test cores.

WBS 1.3.3

PROJECT: Geologic Project Manager (GPM) Program--Permian Basin

PRINCIPAL INVESTIGATOR: Stone & Webster Engineering Corporation (J. Briedis)

ONWI PROJECT MANAGER: G. D. Brunton

OBJECTIVE

The objectives are to plan, manage, and perform geologic and geotechnical investigations to identify and characterize one or more potential radioactive waste repository sites in bedded salts which underlie the Permian Basin, with initial interest in the Palo Duro and Dalhart Subbasins of Texas, and to provide follow-on support if any site is selected by the Department of Energy for development of a repository.

PROGRESS REPORTED PREVIOUSLY

This project was initiated on 10 July, 1980. Previous work involved geologic characterization studies for the Palo Duro and Dalhart Basins, beginning with a survey and summary of available literature on the geology, geophysics, and hydrogeology of the Texas Panhandle. Based on this information, it was concluded that much of the Palo Duro and Dalhart Basins exhibit geologic conditions that are potentially suitable for siting a repository.

More detailed information and stratigraphic data were identified as necessary to further screen the area. A study of available well logs was undertaken to develop basin-wide maps of the thickness and extent of the higher quality salt beds. A minimum thickness specification of 70 feet (including no more than 15 percent of interbedded nonsalt lithologies and with no interbed thicker than 10 feet) was used to screen potential target salt units. Preliminary interpretations of geophysical logs from 165 selected wells were used to identify seven major salt beds and to map their approximate extent within the study area. The areas underlain by at least one target salt unit and recommended for further study were subdivided based on the number of target beds present and an assessment of the relative quality of the salt of each.

ACTIVITIES DURING THE REPORTING PERIOD

A systematic analysis of geophysical logs from oil and gas exploratory wells within the Palo Duro and Dalhart Basins study area was continued. Usable logs have been processed from about 500 wells in Dallam, Hartley, Deaf Smith, Randall, Armstrong, Parmer, Castro, Swisher, Briscoe, Bailey, Lamb, Hale, and Floyd Counties. Each log was studied to determine its formation top and to identify individual salt beds with a thickness greater than 2 feet. The data are input into a computer well file that will allow rapid data manipulation for future studies. The file will also provide computer-generated cross sections and isopach, depth, and structural contour maps of any formation or rock unit for which elevation data have been entered.

The new stratigraphic data have been used to determine the depth, thickness, and lateral extent of the major salt units meeting the 70-foot minimum thickness specification. In addition to the seven target beds previously identified, a unit of adequate thickness was identified within the lower San Andres Cycle 2 salt.

The distribution and characteristics of these major salt beds are summarized in Table 1. Figure 1 shows three portions of the study area that meet the screening specifications. These areas are underlain by one or more salt beds greater than 70 feet thick and of acceptable quality. They are located outside the interpreted zone of active salt dissolution and do not contain sites of oil or gas production. Figure 1 supersedes the figure in the last quarterly report identifying areas recommended for further study.

Table 1. Distribution of Target Salt Beds[a] in the Study Area.

Salt-Bearing Formation (Youngest to Oldest)	Thickness and Extent of Target Salt	Character of Interbeds	Adjacent Strata (U - underlying; O - overlying)	Salt Solution
1. Salado/ Tansill	Hale, Lamb, and Floyd Counties contain a discontinuous target bed that reaches a maximum thickness of 175 ft in SE Hale County.	Discontinuous shale breaks	U - massive Yates red beds O - red beds capped by Alibates	Active solution at position of Caprock Escarpment
2. Seven Rivers	The upper portion of the Seven Rivers, Parmer, Castro, Bailey, Lamb, Hale, and Floyd Counties contains a very discontinuous target bed that reaches a maximum thickness of 150 ft in SW Lamb County. The lower Seven Rivers contains no target bed.	Discontinuous shale breaks	U - red beds, with sandstone, intertonguing with lower salt beds O - massive Yates red beds	At position of Caprock Escarpment and south of Amarillo Uplift
3. Upper San Andres	Includes a widespread target bed throughout most of the Palo Duro Basin with a thickness up to 175 ft in southern Castro County.	Salt units intertongue with anhydrite	U - massive bedded anhydrite (middle San Andres) O - red beds with sandstone	South of Amarillo Uplift, east of Caprock Escarpment
4. Lower San Andres	A Cycle 5 target bed is found in the central and northern Palo Duro Basin. It reaches a 150-ft maximum thickness in Swisher County. The Cycle 4 target bed is continuous across the central and northern Palo Duro Basin. It is a massive bed that reaches a thickness of 175 to 200 ft in Deaf Smith, Randall, and Swisher Counties. It attains an even greater thickness to the north in Oldham County. A Cycle 3 target bed occurs in Deaf Smith and Oldham Counties. It has a 100-ft bed thickness in parts of Deaf Smith County. The Cycle 2 is an isolated target bed occurring in Oldham and Randall Counties. It may also extend into Potter County. The bed is a maximum of 75 ft thick. Cycle 1 has no target beds.	Salt in cycles intertonguing with anhydrite/ dolomite; dolomite with some porosity	U - Glorieta red beds/evaporite O - massive bedded anhydrite Updip (in Dalhart)--Glorieta sandstone	South of Amarillo Uplift, east of Caprock Escarpment
5. Glorieta	There is no target bed at a depth of less than 3000 ft.	Shale interbeds common; anhydrite with shale to south	U - Upper Clear Fork evaporite/shale O - Lower San Andres cyclic units Updip (in Dalhart)--Glorieta sandstone	In central Potter and Carson Counties; possibly to east on south margin of Amarillo Uplift and east margin of Palo Duro
6. Upper Clear Fork	There is no target bed within the Palo Duro Basin. The Cimmaron salt equivalent of the Upper Clear Fork in the Dalhart Basin contains a continuous target bed that is up to 100 ft thick in Dallam County.	Shale interbeds, increase to north; anhydrite increases to south	U - Tubb red beds O - Glorieta red beds/evaporite Updip (in Dalhart)--Clear Fork/Glorieta red beds with sandstone	Possibly on eastern margin, Palo Duro, and Amarillo Uplift
7. Lower Clear Fork	There is no target bed less than 3000 ft deep.	Shale interbeds increase to northwest and southeast; anhydrite/ dolomite increases to south	U - Red Cave red beds O - Tubb red beds Updip - red beds Downdip-anhydrite/ dolomite	No salt solution

(a) A target salt bed is defined as a layer that is at least 70 ft thick, has at least 85 percent salt, has no nonsalt layers thicker than 10 ft, and is between 1000 and 3000 ft deep.

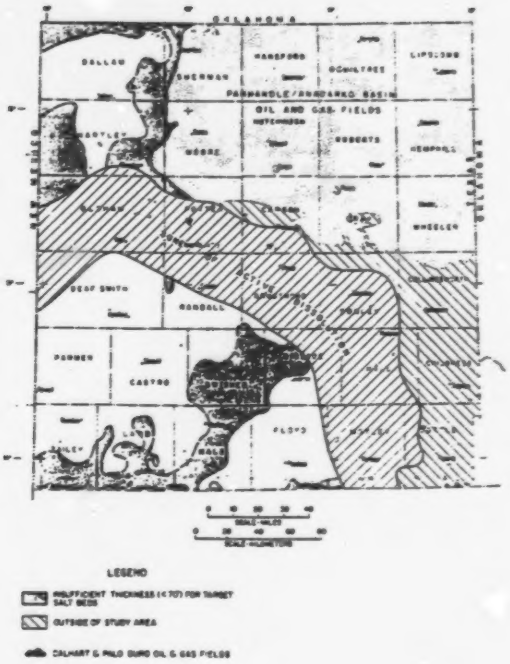

Figure 1. Portion of Study Area Meeting Initial Specifications.

Of the eight target salt beds, the lower San Andres Cycle 4 salt unit appears to be most favorable for repository siting. It reaches the greatest maximum thickness (over 200 feet), contains more massive salt, and appears to be of consistently higher quality over a larger continuous area than any of the other target beds. Figure 2 shows depth contours on the top of the lower San Andres Cycle 4 salt bed within the area meeting initial screening specifications. Figure 3 is an isopach map of this unit within the same area. The salt bed reaches its greatest thickness in parts of Deaf Smith, Randall, and Swisher Counties and occurs at depths ranging from about 2200 feet to 3000 feet.

Hydrogeologic models are being developed for the study area using the new stratigraphic information. At this time there are no results to report; however, some useful generalizations can be made based on preliminary basin-flow studies conducted by TBEG. The TBEG data show that the head in the Wolfcamp limestone, underlying the Permian salt section, is significantly lower than the unconfined freshwater head in the surficial Ogalalla aquifer. Any seepage through the salt sections is downward to the Wolfcamp and then laterally in an easterly direction at a very low rate (estimated less than 13 cm per year). Since the Wolfcamp does not reach the surface within over 100 miles from the study area, nuclide transport from a breached repository to the biosphere would require time periods measured in millions of years.

Drilling of a stratigraphic test well in Donley County began in late June. By the end of the reporting period, it had been cored to a depth of 337 feet. Core recovery in this part of the well was poor due to the very fractured, weathered, and generally unconsolidated nature of the rock. The core obtained was primarily mudstone with occasional anhydrite beds. It is thought to be from a post-San Andres unit of the Permian section which has collapsed due to dissolution of interbedded salt. This well is planned to bottom in Precambrian basement at a depth of about 5000 feet.

FUTURE ACTIVITIES

The following major activities are planned for the next quarter:

- Continue analysis of available geophysical logs and development of the computer file of stratigraphic data. This activity should be essentially completed during the next quarter.
- Develop preliminary hydrogeologic models for the study areas of primary interest.
- Complete drilling of the Donley County well and begin the hydrogeologic testing program in this well.
- Begin drilling a stratigraphic test well in Oldham County.

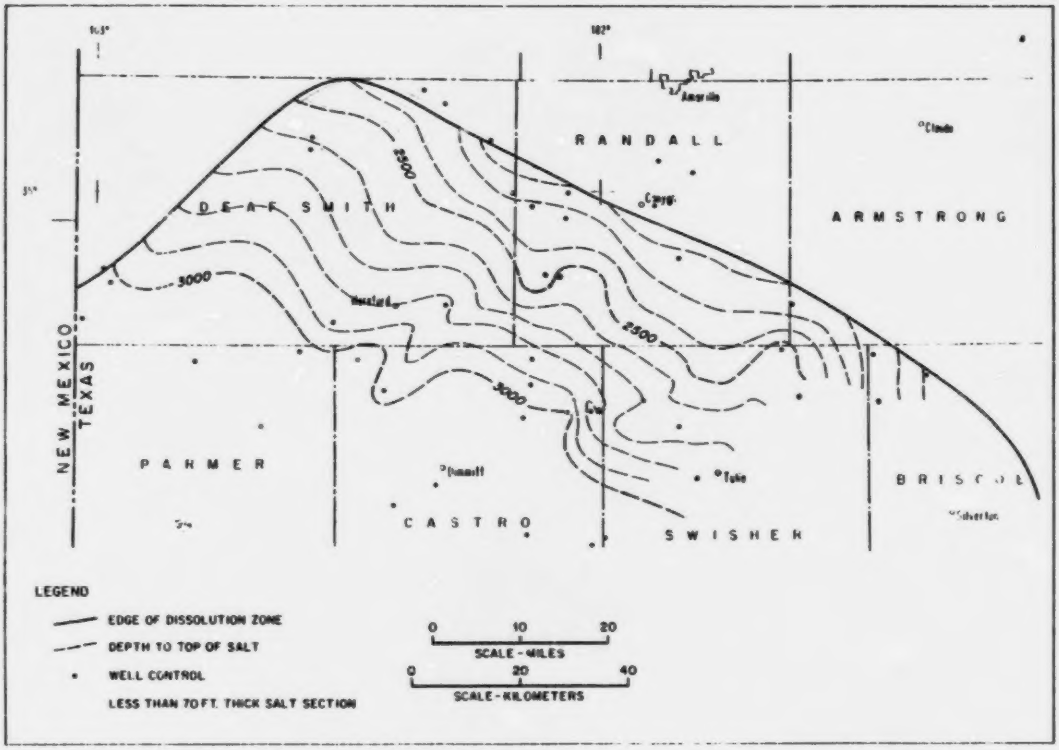
103°
102°
Amarillo
Claude
RANDALL
Canyon
DEAF SMITH
ARMSTRONG
2500
3000
Hereford
2500
3000
NEW MEXICO
TEXAS
PARMER
Dimmitt
Tulia
BRISCOE
CASTRO
SWISHER
Silverton
LEGEND
EDGE OF DISSOLUTION ZONE
DEPTH TO TOP OF SALT
WELL CONTROL
LESS THAN 70 FT. THICK SALT SECTION
0 10 20
SCALE - MILES
0 20 40
SCALE - KILOMETERS

Figure 2. Depth Contours on Top of the Lower San Andres Cycle 4 Salt Unit.

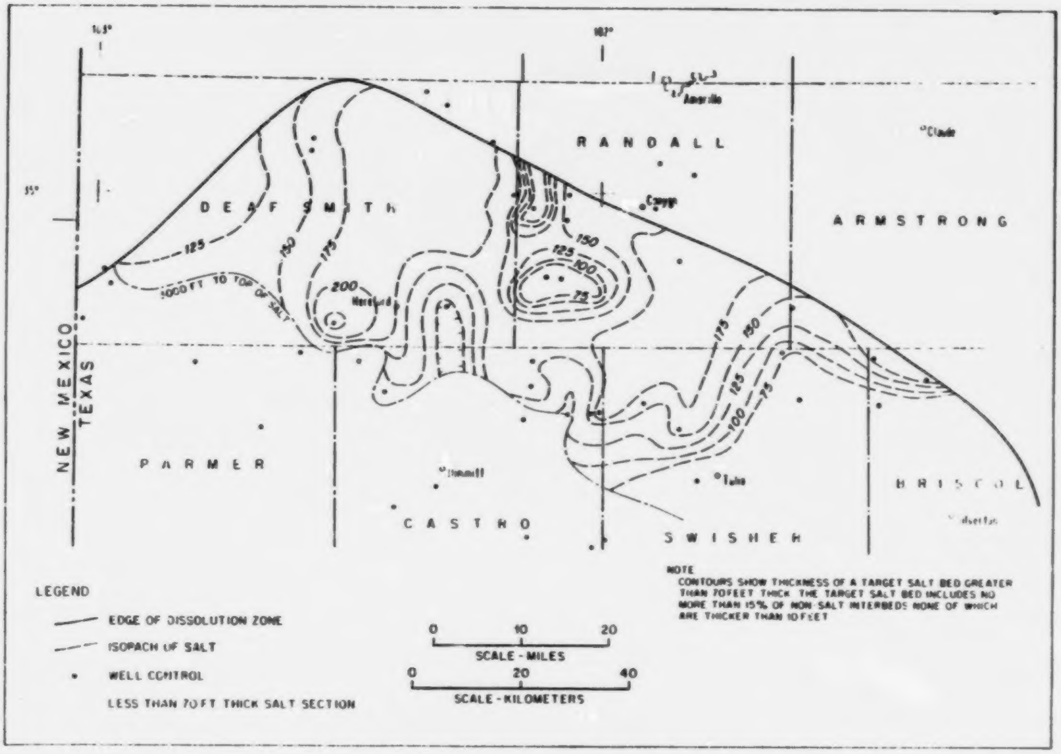
103°
102°
Amarillo
Claude
RANDALL
Canyon
DEAF SMITH
ARMSTRONG
125
150
175
150
125
100
75
3000 FT. TO TOP OF SALT
200
Hereford
175
150
125
100
75
NEW MEXICO
TEXAS
PARMER
Dimmitt
Tulia
BRISCOE
CASTRO
SWISHER
Silverton
NOTE
CONTOURS SHOW THICKNESS OF A TARGET SALT BED GREATER THAN 70FEET THICK. THE TARGET SALT BED INCLUDES NO MORE THAN 15% OF NON SALT INTERBEDS NONE OF WHICH ARE THICKER THAN 10 FEET
LEGEND
EDGE OF DISSOLUTION ZONE
ISOPACH OF SALT
WELL CONTROL
LESS THAN 70 FT. THICK SALT SECTION
0 10 20
SCALE - MILES
0 20 40
SCALE - KILOMETERS

Figure 3. Isopach of the Lower San Andres Cycle 4 Salt Unit.

WBS 1.3.3

PROJECT: East Texas Salt Dome Studies

PRINCIPAL INVESTIGATOR: Texas Bureau of Economic Geology (TBEG) (C. W. Kreitler)

ONWI PROJECT MANAGER: O. E. Swanson

OBJECTIVE

The objectives are to evaluate the potential of East Texas salt domes as hosts for the management of nuclear wastes; to determine whether salt domes and their environs will remain tectonically stable during the active life of nuclear wastes; and to determine whether domes will remain hydrologically stable over the same period of time.

PROGRESS REPORTED PREVIOUSLY

The Bureau began activities in January, 1978. Initial studies concluded that three domes in East Texas (Keechi, Palestine, and Oakwood) merited further study. Since then the Bureau has recommended that Palestine Dome no longer be considered as a candidate dome because of the extensive brining that had previously occurred there. Dome-specific studies have continued on Oakwood and Keechi, as well as generic studies on the rest of the basin.

ACTIVITIES DURING THE REPORTING PERIOD

Meteoric Hydrology

Numerical Modeling. Construction of the Oakwood model is essentially complete. An important finding of the modeling is that the dome is surrounded by relatively muddy facies in the Wilcox, and as a consequence, the model yields ground-water velocities that are 2 to 3 orders of magnitude below normal right around the dome. Other findings include (1) local topography is is probably not capable of causing near-dome short-circuiting flow paths, and (2) the saline plume off Oakwood may be unrelated to the dome since the model has indicated that ground water does not flow in the direction of the plume.

Wilcox Heterogeneity and Core Analysis. Computer and statistical approaches were used to quantitatively measure lithologic connectedness and to examine relationships between connectedness and sand percent in the Wilcox units. The degree of lithologic connectedness varies in different sand-percent regions but not in different Wilcox units. Clean sands are much less connected in low-sand-percent areas than in high-sand-percent areas.

Statistical analysis of grain size, mineralogy, and permeability data from TOH-2A0 core samples from Oakwood Dome was completed.

Point counts of Wilcox sandstones were completed. The sandstones are mainly feldspathic litharenites and lithic arkoses with 50 to 75 percent quartz.

X-ray analysis of bulk shale samples started in April. No calcite has been identified in the shales yet, suggesting that the shales are not the source of calcite causing clay transformations from sodium-montmorillonite to calcium-montmorillonite.

Deep Aquifer Hydrology and Its Effect on Dome Integrity

Water chemistry data were computerized; bad data (based on cation/anion balance) were eliminated; and data have been input into the SPSS statistical program. Preliminary results of the analysis show that the waters are sodium-calcium-chlorine waters and that the addition of calcium occurs only at high sodium-chlorine concentrations.

Pressure data, expressed as pressure-depth figures, indicate that the Woodbine Formation is underpressured (for its depth), whereas the deeper units appear slightly overpressured. The underpressuring of the Woodbine indicates that there is presently no driving potential force that would cause fluids to migrate to shallower horizons.

The Role of Caprock in Preventing Dome Dissolution

Study of caprock samples from additional domes continued this quarter. A sample that apparently is really from under the Oakwood Dome overhang was obtained. It consists of well-oriented, granoblastic anhydrite similar to the caprock on top of the dome.

Samples of caprock from Vacherie, Rayburn's, and other Louisiana domes were studied. The caprock on Vacherie Dome appears to be similar to Oakwood Dome caprock; Rayburn's caprock is similar to Gyp Hill caprock.

Mississippi caprock from Richton and Cypress Creek was also studied. Richton Dome has a false caprock of calcite-cemented sandstone above the real caprock. The caprock consists of an upper calcite zone and a lower anhydrite zone that contains a thick section of gypsum within it. Sulfur is common along fractures.

False caprock over Butler Dome in Texas consists of sandstone cemented by poikilotopic calcite cement. Some fibrous, iron-rich calcite is also present.

Internal Dome Studies

A comprehensive report on the lithology, microstructures, and fluid inclusions of the Oakwood salt core has been prepared.

The average bromide content of halite in the Oakwood rock salt is 44 ppm. This moderately low value suggests that the halite has been chemically recycled by partial resolution by brine after its original precipitation but before the recrystallization episode(s) at the diapir crest that produced the unfoliated R2 and R3 zones. The very low bromide content (22 ppm) of halite in a lens in the caprock suggests that this rock salt precipitated from a brine derived by dissolution of the salt stock.

Structural Studies/Stratigraphy

Basin Stratigraphy. In the Upper Jurassic-Lower Cretaceous studies, isopach, net, and percentage sandstone maps, core descriptions, and petrographic analyses have been completed for the Cotton Valley/Schuler-Hosston clastics. Thickness and facies relationships indicate that early clastic influxes in the northwestern part of the basin initiated salt mobilization due to uneven loading by deltaic depocenters. In the Lower Cretaceous Glen Rose-Paluxy studies, underloading by thick Glen Rose carbonates, the area of greatest salt mobilization, shifted toward the basin center. Depositional patterns of thin Paluxy clastics appear to respond to ongoing salt-related movements. In the Eocene Wilcox clastics, uplift from actively growing shallow salt domes (including Oakwood Salt Dome) during Wilcox deposition locally affected the distribution of fluvial facies by forming local topographically high areas over the diapirs. Calculations of the volume of Wilcox rim synclines indicate that, with respect to ground surface, the rise of the salt diapir compensated for the subsidence of sediment around it.

Preferred Areas of Salt Dome Stability. Volume calculations of salts and sediments infilling salt withdrawal basins are completed. Data have been quantified on the rate of sedimentation and subsidence in salt withdrawal basins and in the whole East Texas Basin. Error bars (±1 standard deviation), mean, mode, median, skewness, kurtosis, and coefficient of variance have been calculated by graphical analyses of cumulative curves.

Basin Tectonics

A large number of subsurface structure maps and graphs of relative and cumulative fault throws have been prepared. Interpretation and data processing are not complete, but some preliminary conclusions may be drawn. The Elkhart-Mt. Enterprise fault system is heterogeneous and relatively complex as compared with the Mexia-Talco fault system. The western end (Elkhart Graben) was most active before the bulk of the faulting at the eastern end (Mt. Enterprise fault). The Elkhart Graben appears to have formed by a combination of crestal rupture over a deep salt pillow, turtle-structure anticlines, and stratal creep northward into the basin and southward into the Gulf. Faults in the center and east, including the Mt. Enterprise fault, differ by being generally younger, by having a large preponderance of down-to-the-north throws, and by not showing any obvious relationship to salt mobilization. Subsurface displacements along the Mt. Enterprise fault show much variation laterally and vertically. This structure, which is shown as a large, single-fault trace on most maps, is therefore a complex of small faults with similar orientations and senses of displacement but greatly varying throws.

The preliminary microseismic investigation continued with the recording of a magnitude 3.2 (Richter) earthquake on 8 June, 1981. The location of this earthquake was determined to be on the Mt. Enterprise fault system at latitude 32.1, longitude 94.4. Also a new microseismic network was set up along the Mt. Enterprise fault system. This network consists of three new recording stations located at Nacagdoches, Rusk, and Cherokee Counties.

FUTURE ACTIVITIES

Additional simulations will be made to test the validity of conclusions regarding the saline plume and effects of heterogeneities. Synthesis of ^{14}C data and measurement of redox parameters will continue. Work will continue on the statistical manipulation of pressure data and water chemistry data. The petrographic study of caprock and false caprock will continue. During the final quarter, a report on the tectonics of the fault system will be prepared and microseismic monitoring will continue in the fourth quarter of this year. A final report on structural studies on the Oakwood salt core will be prepared.

WBS 1.3.3

PROJECT: Gulf Coast Salt Dome Project

PRINCIPAL INVESTIGATOR: Law Engineering Testing Company (D. E. Pauls)

ONWI PROJECT MANAGER: O. E. Swanson

OBJECTIVE

The overall objective of this Geologic Project Manager program is to identify and rank candidate sites for a waste repository. Other scientific investigations have been established by ONWI to evaluate the geologic and hydrologic framework in the study areas of northwest Texas, Louisiana, and Mississippi. The GPM will use the results of these investigations to arrive at conclusions for dome priorities.

PROGRESS REPORTED PREVIOUSLY

This project began on 1 July, 1977. Activities included an evaluation of the geologic and hydrologic framework in the area of three salt domes in Texas (Keechi, Oakwood, and Palestine), three in Mississippi (Cypress Creek, Lampton, and Richton), and two in Louisiana (Rayburn's and Vacherie) and provision of a uniform data base for each of the eight potential domes within these areas. Data acquisition and evaluation continued in support of area characterization. Deep drilling operations for the area characterization phase were completed in Texas, Louisiana, and Mississippi. Pump tests to determine aquifer properties were completed in Texas, Mississippi, and Louisiana.

In all, 222 shallow borings were made in Texas, Louisiana, and Mississippi.

Styrofoam models of the salt stock have been prepared for seven domes, based on purchased and measured gravity data and supplemented by seismic data and well control where available. High-resolution seismic data were used in conjunction with gravity data at both Cypress Creek and Richton Domes to develop detailed analyses of the shallow beds on domal flanks not well recorded by common-depth-point seismic data.

Drafts of the 10-volume geologic area characterization reports for Texas, Louisiana, and Mississippi were completed.

ACTIVITIES DURING THE REPORTING PERIOD

The principal activities being conducted during the quarter were the planning and preparation of drafts, including 12 topical reports, five special project reports, and 15 well completion reports.

The topical reports are expanded versions of subjects dealing with fundamental aspects of salt domes and their geological environments, growing out of the area characterization phase of the Gulf Coast Salt Dome Project.

The well completion reports are factual, detailed summaries of the geological and hydrological data collected from the boreholes drilled in support of the area characterization phase of the project.

The special reports are supplemental studies in support of the area characterization phase of the project.

The following topical reports have been approved: Erosion and Inundation, Mineral Resources Erosion, Existing Boreholes, Cypress Creek Salt Core, and Richton Salt Core. Reports on geothermal studies, gravity studies, groundwater flow time, Hainesville, Northern Louisiana faulting, permeability, and high-resolution seismicity are being prepared. Special draft reports on salt, caprock, and sheath and surface mapping of Keechi, Vacherie, Cypress Creek, and Richton Domes have been written. Well completion reports have been drafted for borings in Mississippi (13 reports) and Louisiana (6 reports).

A draft "strawman" location characterization plan was prepared to describe the geology and hydrology in the area of selected Gulf Coast Interior Basin salt domes to identify potentially suitable sites for a high-level nuclear waste repository.

A draft copy of phases for addressing geologic issues at Vacherie, Cypress Creek, Richton, and Oakwood Domes and a draft location characterization plan were prepared.

FUTURE ACTIVITIES

During the fourth quarter of FY 81, all of the draft topical reports, special project reports, and well completions will be completed. Preparation of a site (location) characterization plan will continue. Water wells in Mississippi and Louisiana will still be monitored. The area characterization reports will be revised.

WBS 1.3.3

PROJECT: Louisiana Salt Dome Studies

PRINCIPAL INVESTIGATOR: Louisiana State University (R. L. Thoms, coordinator)

ONWI PROJECT MANAGER: O. E. Swanson

TASK 1: GEOMECHANICS STUDIES
(R. L. Thoms)

OBJECTIVE

The general objective is to monitor and analyze any possible ongoing movement that can be associated with salt domes. Thus, this study deals with the current tectonic stability of Vacherie and Rayburn's Domes in north Louisiana.

PROGRESS REPORTED PREVIOUSLY

Geomechanics studies have included monitoring of any current ongoing movement over Vacherie and Rayburn's Domes with a complementary system of field instrumentation and numerical modeling. These studies include: (1) tiltmeters, (2) precise releveling, (3) corehole closure monitoring, (4) seismicity monitoring, (5) microseismic monitoring, (6) numerical modeling, and (7) the planning of laser ranging systems.

Of the above-listed seven items, major emphasis has been placed on tiltmeters, precise releveling, and corehole closure monitoring. Some work also has been performed on microseismic and seismic monitoring at Rayburn's and Vacherie Domes, respectively.

Progress reported previously included preparation of a draft report on corehole closure at Vacherie and Rayburn's Domes. Analysis of tilt data over the dome was continued, and a report on numerical modeling of Rayburn's is being prepared.

ACTIVITIES DURING THE REPORTING PERIOD

A preliminary draft report on corehole closure at Vacherie and Rayburn's Domes includes closure data collected at the sites of the two coreholes through September, 1980. Caliper surveys of the coreholes are currently planned for completion in late summer, 1981.

The draft report on numerical modeling of possible vertical movement of Rayburn's Dome is essentially complete.

Tiltmeter data are being processed and put in a final form for analysis. The last set of tilt data will be retrieved from the Vacherie Dome area around the end of June, 1981.

FUTURE ACTIVITIES

Precise releveling will be performed over a network of surveying monuments at Vacherie Dome. In addition, caliper surveys will be performed in the coreholes in Vacherie and Rayburn's Domes.

TASK 2: GEOHYDROLOGY STUDIES
(M. B. Kumar)

OBJECTIVE

The objectives are (1) to determine the hydrologic stability of north Louisiana salt domes, and (2) to study the hydrologic isolation of mined openings in salt domes.

PROGRESS REPORTED PREVIOUSLY

Geohydrology studies have included the drilling of seven exploratory observation wells. A possible saline plume was detected to the east and southeast of Vacherie Dome (no such plume was observed in the vicinity of Rayburn's Dome). Numerical modeling activities have been under way to simulate domal saline plumes. An investigation of possible salt springs in the dome areas has been initiated. Several existing salt mines in the Gulf Coast were studied for leaks.

The chemical and isotopic analyses of the water from the leaks at the Belle Isle, Weeks Island, and Jefferson Island salt mines strongly indicate that the mine brines are formation waters. A similar investigation has been in progress for the Avery Island salt mine. A technique was developed to conduct routine measurements of ±0.002 weight percent water in salt. Measurements of water content of several samples of salt and sandstone inclusions were made. A report about the trace water content of salt in Louisiana salt domes was prepared for publication.

The study of the recent flooding of the Jefferson Island salt mine was initiated.

ACTIVITIES DURING THE REPORTING PERIOD

Jefferson Island Mine Flooding Study

The study of the recent flooding of the Jefferson Island salt mine was continued. A preliminary geologic cross section through the collapse feature and the mine shaft was constructed, incorporating available well data. Preliminary computations were made to estimate the discharge and velocity of water at the bottom of the collapse feature, as well as the size of the collapse. From electric logs of wells, data have been developed on the interface between the fresh and saline water in the aquifers. Other pertinent hydrologic data are being compiled.

Hydrologic Isolation of Mined Openings

The mine leaks study has been in progress. The data developed thus far on the Avery Island salt mine are being evaluated. Related chemical analysis of mine brines has resumed.

Surface Water Salinity (Salt Springs) Study

As a continuation of the salt springs study, a literature survey on related topics was initiated. This will aid in evaluating the field data obtained thus far.

Numerical Modeling of Domal Saline Plumes

Numerical modeling activities pertaining to domal saline plumes were continued. A topical report on a three-dimensional mathematical model for evaluation of domal salt transport by ground water involving the principles of computations and a user's manual was drafted and submitted. In addition, a brief literature survey was conducted to compare the LSU domal salt transport model with other numerical models, and a report on this has been submitted.

FUTURE ACTIVITIES

The numerical modeling of domal saline plumes will be continued, with emphasis on sensitivity analyses of the significant parameters involved and verifications with ORNL's AT123D model. The future salt spring study will comprise further investigations of the surface waters in the Vacherie area with anomalously high chlorinity values observed during the preliminary examinations. Detailed sampling of the surface waters in the Rayburn's area is also planned. The mine leak study will include an appraisal of new data from the current chemical and isotopic analyses of brine samples. The ongoing study of the Jefferson Island mine flooding will be completed following a review of the Mine Safety and Health Administration report.

TASK 3: REGIONAL GEOLOGY

(R. E. Wilcox)

OBJECTIVES

The objectives of this study are (1) to determine the petrology, mineralogy, and geochemistry of salt and caprock from Vacherie and Rayburn's domal cores; (2) to appraise the tectonic stability of salt domes in north Louisiana; and (3) to study the sizes and shapes of Vacherie and Rayburn's Salt Domes, Webster and Bienville Parishes, Louisiana.

The primary emphasis and research efforts will focus on the first objective during FY 81.

PROGRESS REPORTED PREVIOUSLY

Studies of regional structure and stratigraphy of the north Louisiana salt dome basin were completed in previous years, as were several seismic studies of Vacherie Salt Dome, reports on the lithology of salt cores from Vacherie and Rayburn's Domes, and chemical analyses of salt core samples. Mathematical approaches to the inverse-density interpretation of gravity data over salt domes were developed.

Initial detailed studies of Vacherie and Rayburn's core layering using petrographic and geochemical techniques have included dissolution studies of salt and caprock samples, the selection of 161 salt and caprock samples from Vacherie and Rayburn's cores for detailed petrological and geochemical studies, and exploratory atomic absorption (AA) analyses of two different salt textures.

Work last quarter included continuing petrological studies of the salt cores and resumption of analyses of salt samples from the Vacherie core following the installation of the AA in temporary quarters pending completion of the new geochemical laboratory.

ACTIVITIES DURING THE REPORTING PERIOD

During the quarter, 70 samples of the Vacherie core were analyzed for sodium, calcium, potassium, magnesium, and SO_4. A few samples have been analyzed for Cl^-, but the precision is not yet satisfactory. The AA required several repairs, and new lamps were purchased for calcium and strontium. The repairs and the new lamps have resulted in precision for Na at less than 3 percent, for Ca at less than 5 percent, and for Sr at 10 ppm at less than 5 percent. The precision for K at 20 ppm is only 20 percent. Instrument precision for Mg at 10 ppm is approximately 10 percent; however, the sample triplicate precision can be as high as 100 percent. This very poor precision does not appear to be an analytical problem; it is probably related to sample homogeneity. In the thin sections, traces of dolomite occur in some samples, usually as minute, single euhedral crystals. The crystals are of a size that could escape pulverization, and one such crystal in one of the sample splits could be enough to cause the observed large variation in Mg content.

Preliminary interpretations indicate differences in the $CaSO_4$ content in various textures; this also has been observed petrographically. However, there also appears to be a correlation between some of the textures and the Ca/Sr ratios.

Throughout the geochemical studies, there has been considerable concern about the contamination introduced by the drilling fluids and the early storage conditions of the core. In order to check for contaminations, pairs of samples were selected. Each pair included one sample selected from the outer edge of the core and another sample from the center of the core. In each of the three cases, no detectable contamination was observed when the sample pairs were analyzed for the same constituents by standard methods used for the salt cores.

The Texas Bureau of Economic Geology had some positive results from a strain analysis study applied to the Oakwood Salt Dome. A similar strain analysis was begun on the Vacherie salt core using the following method. For each section of core, three perpendicular cuts are made, one of those being parallel to layering, when possible. For salt crystals on each cut, three measurements are taken: the length of the long axis, the length of the short axis, and the angle of the long axis to a defined line. For each cut, a thin section also will be made. This information is being stored in the computer to be available for future calculations.

A fluid inclusion heating/freezing stage and a crushing stage may be used on the microscope in the studies of fluid inclusions in salt.

FUTURE ACTIVITIES

Work will continue on the petrology and geochemical analyses of the core samples previously selected from Vacherie and Rayburn's Salt Domes.

TASK 4: QUATERNARY STUDIES

(C. R. Kolb)

OBJECTIVE

The objectives have been (1) to determine whether the Quaternary has been lifted out of place above Rayburn's and Vacherie Domes by upward movement of the salt since deposition of these sediments between 5,000 and 500,000 years ago; (2) to provide insights concerning the hydrologic stability of the upper portions of the domes as evidenced by dissolution and subsidence and/or collapse during Quaternary time; (3) to estimate the effects of erosion above the domes during the next 250,000 years; and (4) to use boring, trenching, and related data to determine the stratigraphy and structure above the domes.

PROGRESS REPORTED PREVIOUSLY

Incomplete studies to date have shown: (1) no evidence of tectonic uplift over Vacherie Dome during Quaternary time; (2) possible minor dissolution and subsidence above Vacherie and more significant dissolution over Rayburn's during the Quaternary (recent pollen studies indicate dissolution of Rayburn's Dome of 1 foot per 1000 years during the last 15,000 years); and (3) a maximum of 120 feet of erosion can be expected at both sites during the next 250,000 years.

Borings (20 to 200 feet deep) above the domes have penetrated unusually deep Quaternary deposits. These deposits suggest dissolution and collapse or subsidence of the upper part of the domes--a minor amount over Vacherie Dome during the Quaternary, and more than 100 feet over Rayburn's Dome during this period. Complicating matters are deep "anomalous" sands beneath the known Quaternary at Vacherie and a thick calcitic boulder zone above anhydrite caprock at Rayburn's. It is uncertain whether these strata are of Quaternary or pre-Quaternary age.

Work during the preceding quarter included (1) completion of pollen studies from Vacherie and Rayburn's and of a topical report summarizing the data and results; (2) continuation of laboratory analyses of cored and washed samples; (3) completion of the plans and specifications for the restoration of the corehole sites at Vacherie and Rayburn's; and (4) continuation of work on the summary report for Rayburn's and of the grain-shape and grain-surface studies.

ACTIVITIES DURING THE REPORTING PERIOD

Work began on restoration at the Rayburn's site on June 29. It is anticipated that restoration work at both Rayburn's and Vacherie will be completed some time in July.

The laboratory core and washed sample analyses of the Rayburn's borings made in FY 80 were completed in May. These data are being systematically worked into plans and sections of the Rayburn's summary report. A cross-reference location system of all boxed samples from both the Rayburn's and Vacherie sites has been completed. The system was developed in cooperation with Quality Assurance, and a "location map" permits quick retrieval of any sample needed.

A report on isotopic evidence of the origin of the Rayburn's boulder zone concludes that on the basis of isotopic carbon and oxygen content, the boulder zone at Rayburn's results from the weathering and alteration of a former calcite caprock cover above the dome.

FUTURE ACTIVITIES

Next quarter's activities will include (1) completion of data analyses and the summary report on Rayburn's; (2) a report on the grain-shape and grain-surface studies at Vacherie; (3) a file report on the Gulf Coastal Plain terrace concept; and (4) Rayburn's and Vacherie site restorations and a summary report on these restorations.

WBS 1.3.3

PROJECT: Louisiana Hydrology

PRINCIPAL INVESTIGATOR: U.S. Geological Survey, District Office, Baton Rouge, Louisiana (G. N. Ryals)

ONWI PROJECT MANAGER: O. E. Swanson

OBJECTIVE

The objective is to compile regional geohydrology maps for the northern Louisiana Salt Dome Basin and to conduct hydrologic field studies, data collection, and analyses near Vacherie and Rayburn's Salt Domes. A regional, multilayered ground-water flow model will be designed.

PROGRESS REPORTED PREVIOUSLY

Potentiometric surface maps of the Sparta and the Wilcox-Carrizo aquifers, a base-of-freshwater map of the northern Louisiana Salt Dome Basin and vicinity, and selected hydrologic data from the vicinity of Rayburn's and Vacherie Salt Domes were published.

ACTIVITIES DURING THE REPORTING PERIOD

During the past quarter, work objectives were to (1) maintain the ongoing ground- and surface-water data collection network, (2) analyze geologic and hydrologic data from the area characterization test drilling activities, (3) begin preparing a report to summarize the USGS regional study and data needs in north Louisiana, and (4) participate in location, characterization, and planning activities for Vacherie Salt Dome. More data are needed to develop a regional ground-water flow model.

FUTURE ACTIVITIES

Data from the area characterization test drilling program will be analyzed. Although these data are not sufficient for a detailed regional, multilayered ground-water flow model, developmental work on a skeletal ground-water flow model will begin. A report will be prepared to summarize the regional study and data needs in north Louisiana.

WBS 1.3.3

PROJECT: Mississippi Hydrology

PRINCIPAL INVESTIGATOR: U.S. Geological Survey, Water Resources Division (WRD), District Office, Jackson, MS (P. A. Dooley)

ONWI PROJECT MANAGER: O. E. Swanson

OBJECTIVE

The objective is to describe the geohydrology of the Mississippi Salt Dome Basin and nearby selected domes with respect to the direction and rate of ground-water flow.

PROGRESS REPORTED PREVIOUSLY

This project began in July 1977. A summary of activities during the preceding quarter is as follows:

1. Development of a preliminary conceptual model depicting geohydrologic conditions near Cypress Creek and Richton Salt Domes, Mississippi.
2. Development of baseline empirical relations that can be used to estimate water quality in selected Tertiary aquifers in southeastern Mississippi.

ACTIVITIES DURING THE REPORTING PERIOD

Work began on preliminary reports of the geohydrology near Cypress Creek and Richton Salt Domes and the use of geophysical logs for estimating water quality and porosity in Tertiary formations of southeastern Mississippi.

FUTURE ACTIVITIES

Work will continue on the reports, and a work plan for FY 82 will be developed.

WBS 1.3.3

PROJECT: Lake Superior Region Granitics

PRINCIPAL INVESTIGATOR: Sandia National Laboratories (D. W. Powers)

ONWI PROJECT MANAGER: R. R. Nicks

OBJECTIVE

The objective of this program is to screen a previously identified granitic region in the Lake Superior district to identify areas which are favorable for further characterization. The screening program will use only existing data; no field exploration activities will be conducted during region-to-area screening. The final objective is to provide a report which identifies areas (within the region) that are favorable for further characterization.

PROGRESS REPORTED PREVIOUSLY

This project began on 9 June, 1980. Case structures were activated, literature searches were initiated, and screening criteria were reviewed. Literature searches and a criteria review were conducted. GEOREF, an on-line computer bibliography, was searched, and it produced an extensive bibliography which supplements the references to the geotechnical literature of the Lake Superior district before 1960. Literature was ordered from the Minnesota Geological Survey.

The literature survey continued, although at a slow pace, and initial failure scenarios were examined for relevance to granite screening.

ACTIVITIES DURING THE REPORTING PERIOD

The literature search and review has been continued, principally for the state of Minnesota. Examinations were made in detail of the literature on better known areas of crystalline rocks in Minnesota: the Minnesota River valley, the St. Cloud instrusives, and the Vermilion complex. The initial comparison of rock types, availability of information, and potential failures has helped to focus on the screening difficulties for the region as a whole.

Potential failure scenarios for the Lake Superior region were examined further to determine which geotechnical criteria from DOE/NWTS-33(2) are most important. This activity will produce values for screening criteria which are conditioned by the regional geology and will indicate important objectives for the next level of characterization.

Deficiencies exist in the data for deep hydrology that are quite important for the screening process. Therefore, the screening process will probably identify suitable areas of crystalline rocks for a study of deep hydrology.

FUTURE ACTIVITIES

The principal activities in the next quarter will be to complete the literature survey and failure scenarios.

REFERENCE

U.S. Department of Energy, 1981. NWTS Program Criteria for Mined Geologic Disposal of Nuclear Waste: Site Performance Criteria, DOE/NWTS-33(2), Office of NWTS Integration, Battelle Memorial Institute, Columbus, OH, February.

WBS 1.3.5

PROJECT: Environmental Characterization--Permian Basin

PRINCIPAL INVESTIGATOR: NUS Corporation (J. DiNunno and W. Belter)

ONWI PROJECT MANAGER: D. J. Guzzetta

OBJECTIVE

The objective is to conduct environmental studies at the regional, area, and location levels as a means of identifying environmental aspects of concern or interest in relation to the geologic formation of interest. The studies provide a means of identifying sites that may be potentially the most suitable for a repository as well as documenting the base data to be used in subsequent licensing documents such as Environmental Reports.

PROGRESS REPORTED PREVIOUSLY

The characterization tasks were begun on 7 July, 1977. A subregional summary and area recommendation report for the Permian Region was initiated. An environmental evaluation for exploratory drilling in the Permian Basin was reviewed.

ACTIVITIES DURING THE REPORTING PERIOD

A Permian planning committee initiated work on the identification of locations within the Permian suitable for further study. The process of location selection was still ongoing at the end of this quarter.

Planning for location phase environmental characterization work was initiated.

NUS prepared a report evaluating the Texas Panhandle portion of the Ogallala aquifer and its potential relationship and use in nuclear waste repository site selection. The report summarizes the available literature.

WBS 1.3.5

PROJECT: Environmental Characterization--Paradox Basin

PRINCIPAL INVESTIGATOR: Bechtel Group, Inc. (N. A. Norman)

ONWI PROJECT MANAGER: F. L. Moleski

OBJECTIVE

The objective is to conduct environmental studies at the regional, area, and location levels as a means of identifying environmental aspects of concern or interest in relation to the geologic formation of interest. The studies provide a means of identifying sites that may be potentially the most suitable for a repository as well as documenting the existing baseline conditions to be used in subsequent licensing documents such as environmental reports.

PROGRESS REPORTED PREVIOUSLY

The characterization tasks were begun in December 1977. Regional environmental activities have been completed. Reports concerning this phase of siting were written: Regional Environmental Characterization Report for the Paradox Bedded Salt Region and Surrounding Territory (ONWI-68) and Summary Characterization and Recommendation of Study Areas for the Paradox Basin Study Region (ONWI-36, public draft). The environmental characterization of the four study areas within the Paradox Region has been completed. The Environmental Characterization Report for the Paradox Basin Study Region-Utah Study Areas (ONWI-144, public draft), was prepared.

ACTIVITIES DURING THE REPORTING PERIOD

The draft area study report (ONWI-144) describing environmental characteristics at Salt Valley, Lisbon Valley, Gibson Dome, and Elk Ridge was issued for public review and comment. Information presented in the area characterization report is being used to select locations for further study as potential nuclear waste repository sites.

WBS 1.3.5

PROJECT: Environmental Characterization--
Gulf Coast Salt Domes

PRINCIPAL INVESTIGATOR: Bechtel Group, Inc.
(N. Norman)

ONWI PROJECT MANAGER: R. B. McPherson

OBJECTIVE

The objective is to conduct environmental studies at the regional, area, and location levels as a means of identifying environmental aspects of concern or interest in relation to the geological formation of interest. The studies provide a means of identifying sites that may be potentially the most suitable for a repository as well as documenting the base data to be used in subsequent licensing documents such as environmental reports.

PROGRESS REPORTED PREVIOUSLY

The characterization tasks were begun in July 1977. Two final reports related to the Gulf Coast were received from Bechtel: Regional Environmental Characterization Report for the Gulf Interior Region and Surrounding Territory (ONWI-67) and Summary Characterization and Recommendation of Study Areas for the Gulf Interior Region (ONWI-18).

A meeting was held at ONWI with Gulf Coast state representatives to discuss the Site Characterization Plan (SCP) schedule and state involvement. As a result of this meeting, Bechtel began the environmental sections of the SCP.

Assembly and testing of equipment for environmental field work was completed. This equipment will be stored until site studies begin.

ACTIVITIES DURING THE REPORTING PERIOD

Draft area study reports describing environmental characteristics at salt domes in Louisiana (ONWI-192), Mississippi (ONWI-193), and Texas (ONWI-194) were issued for public review and comment. Information presented in the area characterization reports is being used in selecting several salt domes for further study as potential nuclear waste repository sites.

A preliminary evaluation of economic impacts at Richton Dome in Mississippi was received from Bechtel.

A working paper version of the SCP was submitted to ONWI in April for review by the states. This report describes the procedures to be used to characterize candidate repository sites in the Gulf Region; it also provides an overview of the decision process leading to site selection and a review of site selection criteria and screening guidelines. Issues of major concern to each state were identified during the quarter for inclusion into dome-specific location characterization plans now being prepared. A revised draft is expected in July.

Site characterization planning workshops were held with state representatives in Texas, Louisiana, and Mississippi during June.

WBS 1.3.5

PROJECT: Regional Environmental Characterization--Northeast Region

PRINCIPAL INVESTIGATOR: Battelle Pacific Northwest Laboratories (I. C. Nelson)

ONWI PROJECT MANAGER: N. J. Beskid

OBJECTIVE

The objective of this task is to prepare an environmental characterization of the Northern Appalachian Region, which is comprised of portions of the states of Connecticut, Maine, Massachusetts, New Hampshire, New Jersey, New York, Pennsylvania, Rhode Island, and Vermont. The region will be screened to prepare an analysis for and recommendations of areas within that region that are suitable candidates for more detailed geologic and environmental characterization.

PROGRESS REPORTED PREVIOUSLY

This project began on 10 March, 1981. Reference documents for the Northeast region were obtained using the Region Survey Plan, the Salina Basin study (Office of Nuclear Waste Isolation, 1979), and the Paradox Basin Study (Bechtel National, Inc., 1980) as bibliographic sources. Project staff examined the ORNL Geoecology Data Base and will be using this system to augment the reference documents.

ACTIVITIES DURING THE REPORTING PERIOD

Baseline information was gathered from Pennsylvania, New Hampshire, New York, Massachusetts, and Connecticut. The boundaries of the study region were delineated by BPNL and ANL (ANL is conducting a companion geologic study).

ORNL-7351, Geoecology: A County-Level Environmental Data Base for the Conterminous United States, was sampled and will be used to augment information obtained directly from the states.

FUTURE ACTIVITIES

The remainder of the states will be visited, to the degree possible, during the next quarter, and preparation of a draft characterization report will begin.

REFERENCES

Bechtel National, Inc., 1980. Environmental Characterization Report for the Paradox Basin Study Region Utah Study Areas, ONWI-144, Office of Nuclear Waste Isolation, Battelle Memorial Institute, Columbus, OH.

Office of Nuclear Waste Isolation, 1979. Environmental Characterization of Bedded Salt Formations and Overlying Areas of the Salina Basin, ONWI-16, Battelle Memorial Institute, Columbus, OH, September.

WBS 1.3.5

PROJECT: Regional Environmental Characterization--Southeast Region

PRINCIPAL INVESTIGATOR: Oak Ridge National Laboratory (J. R. Krummel and S. G. Hildebrand)

ONWI PROJECT MANAGER: N. J. Beskid

OBJECTIVE

The objective of this task is to characterize the environment of the Southern Piedmont Region that includes a number of granitic formations which have geologic characteristics potentially suitable for permanent disposal of nuclear wastes. The region will be screened, using environmental criteria, in order to identify the most favorable areas for further study. This task supports the ONWI overall goal of providing a significant degree of assurance that high-level nuclear wastes can be isolated from the biosphere in a safe and environmentally acceptable manner.

PROGRESS REPORTED PREVIOUSLY

This project began on 1 March, 1981. Locations and type of granite within the study region were digitized for use in computer mapping and statistical analysis. The U.S. Geological Survey NASQAN (National Stream Quality Accounting Network) water quality data were made compatible with the ORNL Geoecology Data Base for water quality analysis. The water quality analysis gathered water-basin-level information associated with sediment, nutrient levels, leached salts, and other parameters that affect aquatic biota. Ecosystem data related to both managed and natural systems were compiled during this reporting period. Important agricultural and forest resources in the region were mapped to judge critical resources for the area evaluation. The region has small amounts of cropland, but contains extensive pasture and commercial forest stands.

ACTIVITIES DURING THE REPORTING PERIOD

The environmental data base for the regional characterization is approximately 95 percent complete. Sources of information have included federal agencies, natural resource offices, the open literature, and computerized data bases. The spatial level of the acquired data included two basic types: (1) county-level data and (2) other spatial levels dictated by the type of information presented for display on base maps and tables. Spatial information not available and/or accessible for computer manipulation has been refined for use on a standard base map or in appropriate tables.

All data have been aggregated to the Water Resources Council regions and subregions. Data analysis has focused on annual freshwater uses in 1975, with projections to 2000, and the U.S. Geological Survey's WATSTORE data base. Maps and tables are being completed that list water quality variables. Information has been obtained and analysis started on wetlands, navigable waterways, and lakes and impoundments in the study region. Work has also begun on analyzing the important aquatic species and habitats, including commercial fisheries and threatened and endangered species.

For analysis of terrestrial ecosystems, the 1978 Census of Agriculture was used to map the distribution of cropland area, important livestock areas, and prime farmland in the Southern Piedmont. For analysis of natural ecosystems, the Geoecology Data Base at ORNL was used. It includes integrated data on natural vegetation, threatened and endangered species, and regional bird and mammal species. Much of this information has been mapped for use in the selection criteria for screening for areas.

State offices have been contacted in Maryland, Virginia, North Carolina, South Carolina, and Georgia for information on state-administered public lands. State wildlife refuges, parks, historical areas, and other state-related data are being displayed on base maps. In addition, state-level information on Indian reservations and major airports and traffic corridors has been obtained.

Important climatic information, such as 30-year mean annual and monthly values for precipitation (by county), has been analyzed and displayed on base maps. The National Oceanic and Atmospheric Administration data used to calculate wind speeds, severe weather, suspended dust, and wind erosion potential will be utilized in conjunction with information obtained from the USGS to map terrain-climatic interactions. Air quality parameters, such as SO_2 and ozone concentrations, were derived from the Geoecology Data Base and the U.S. EPA. Ambient levels of air pollutants and noncompliance areas in the study region are being mapped.

FUTURE ACTIVITIES

Analysis of the regional environmental data will be completed in the next quarter. A draft of the summary report will combine the regional environmental characterization with the geologic information obtained from work completed by the Savannah River Laboratory. A matrix system, using criteria developed by NWTS, will then list areas for further study for nuclear waste disposal.

WBS 1.3.5

PROJECT: Regional Environmental Characterization--North Central Region

PRINCIPAL INVESTIGATOR: Argonne National Laboratory (J.L.S. Saguinsin)

ONWI PROJECT MANAGER: N. J. Beskid

OBJECTIVE

The objective of this project is the environmental characterization of the North Central (Lake Superior) Region, including the upper peninsula of Michigan and the states of Minnesota and Wisconsin. This is an initial step in an orderly process of identifying favorable locations for nuclear waste terminal storage sites.

The major elements of the project are (1) collection of relevant environmental data, (2) preparation of regional characterization, and (3) preparation of a summary with recommendation for area studies.

PROGRESS REPORTED PREVIOUSLY

Work on this project began on 2 December, 1980. Data collection was performed using sources of information identified in the Region Survey Plan and other sources.

ACTIVITIES DURING THE REPORTING PERIOD

Changes and improvements to the generic region survey plan have been transmitted to ONWI.

WBS 1.3.7

PROJECT: Study of Morro do Ferro

PRINCIPAL INVESTIGATOR: New York University Medical Center (M. Eisenbud)

ONWI PROJECT MANAGER: N. Hubbard

OBJECTIVE

The objective is to quantify the rates of natural transport of thorium, uranium, rare earths, barium, and radium from a massive 80 million-year-old deposit located near the summit of a hill (the Morro do Ferro) in the Pocos de Caldas plateau, in the state of Minas Gerais, Brazil. The site is being characterized geologically and geochemically. The primary objective is to use thorium as an analog for plutonium, thereby permitting development of improved mobilization models for that element because thorium is an actinide with chemical properties similar to plutonium in the +4 state. Rare earths will also be studied for mobility as possible analogs for other actinides. Radium mobilization studies are included along with its analog, barium.

PROGRESS REPORTED PREVIOUSLY

The project began on 1 October, 1979. In the first year of study, thorium mobilization was assessed by (1) measuring thorium concentration in the water and suspended solids of a stream draining the Morro do Ferro basin, and (2) by analyzing dated cores from alluvial deposits in the drainage basin. A flume has been constructed in the stream channel and equipped with a continuous flow recorder and composite water sampler. The mean total thorium concentration from July, 1979 to October, 1980 was 0.39 µg/ℓ, with a standard error of 0.07 µg/ℓ. To a first approximation, the estimated mobilization rate of the thorium deposit was 4.0×10^{-8} per year. The average life of the thorium deposit, assuming the present rate of mobilization, would thus be about 25 million years.

Results of swamp core and soil sample analyses were reported. The thorium concentration range in the swamp was 10 to 300 µg/g. Soil samples from all of the Morro do Ferro basin including the ore body ranged from 90 to 12,500 µg/g.

The isotopic equilibrium between ^{232}Th and ^{228}Th was demonstrated to be unity in 16 soil and core samples from the Morro do Ferro basin.

Concentration ranges in soil for thorium, uranium, lanthanum, cerium, praseodymium, neodymium, promethium, samarium, iron, zirconium, and barium were presented.

ACTIVITIES DURING THE REPORTING PERIOD

Thin section studies by scanning electron microscopy (SEM) coupled with energy dispersive analysis by X-ray (EDAX) have been performed on rock core samples preserved from past exploration work. The depth of the core samples is from 150 to 200 m so that the thin section material is of relatively fresh rock. Thorium was found to be contained in zircon, monazite, and cheralite, a monazite-like mineral. The monazite and cheralite are both present as grains of 1 to 5 µm dimensions appearing as aggregates of 10 to 50 µm in diameter. The individual cheralite crystals are smaller, 1 to 5 µm, but also occur agglomerated in veins with dimensions of 10 x 100 µm.

Thorium is a major constituent of cheralite. Up to 50 percent of the oxide has been seen in thin sections, and concentrations of up to 30 percent have been reported elsewhere. The habit of the cheralite, which appears to be the dominant host for the thorium, is suggestive of its being secondary, although quite possibly as a late stage in the intrusive cycle. Cerium is the dominant rare earth in the cheralite.

An evaluation of the theoretical relative stabilities of Th(+4) and Pu(+4) complexes has been performed using data taken from the literature. Ligands considered in the evaluation included F^-, SO_4^{2-}, HPO_4^{2-}, citrate, and ethylenediaminetetraacetic acid (EDTA). Despite the uncertain quality of some of the data, there is a striking similarity in the equilibrium constants computed for the reactions:

$$M^{4+} + L^{n-} = ML^{4-n} \ (k_1) \text{ and } ML^{4-n} + L^{n-} = ML^{4-2n} \ (k_2) \quad .$$

Except for the sulfate complexes, the differences are in the direction that would be expected theoretically: slightly more stable complexes for Pu^{4+}, because its ionic radius (0.98 A) is a little smaller than that of Th (1.07 A). Especially notable in the evaluation were high equilibrium constants for the two organic compounds, reflecting the fact that for both thorium and plutonium, mobility is markedly enhanced by the presence of organic materials.

Analysis of elemental correlations with thorium in soils and sediments from the Morro do Ferro basin and the ore body have yielded the following trends. Good correlation ($r > 0.80$) is observed for all the rare earths on the ore body as quantified by X-ray fluorescence (XRF). The rare earths with the good association are Ce, Pr, Nd, Pm, and Sm. In the swamp, a good correlation is observed only between thorium and cerium. The good correlation between Th and Ce in the macroanalysis of bulk soil material agrees well with the SEM-EDAX results on the microscale.

The implication of these results is that the cheralite present deep in the ore body site is maintaining its mineralogical integrity since the primary rare earth in the mineral is cerium. The rare earth phosphates, which include monazite and cheralite, are known to be highly refractory and thus resistant to environmental weathering conditions. If cheralite can be identified in the surface soil and in the suspended solids fraction of the water column in the stream that drains the basin, this would explain the good correlation of Th with Ce elsewhere in the basin.

Experiments are being planned to assess whether the cheralite can account for the majority of the thorium observed in macrosamples.

Supporting Research

Optimization of the XRF system designed in the laboratory has been completed. The accuracy of the overall system has been verified by analyses of standardized rock samples received from the USGS. The lower limit of detection for thorium, uranium, cerium, and lanthanum are 21, 12, 10, and 11 μg/g, respectively. These limits apply to 1000 s count times and about 7.5 g samples. The sensitivity can be improved by longer counts, but a 1000 s count is adequate for the time being.

A mangenese dioxide coprecipitation method has been adopted from the literature to facilitate extraction of thorium, uranium, and quite possibly rare earths from water samples. The technique is currently under development and if successful will streamline the current water processing method which requires the evaporation of up to 19 ℓ of filtered water to preconcentrate the thorium and uranium in this fraction.

FUTURE ACTIVITIES

Fourth quarter activities will include three studies:

- Further investigation into the mineralogical state of the thorium and rare earths in soil and sediment samples
- Collection and analysis of fresh phonolites from the Pocos de Caldas plateau to ascertain if the caldera rim material is cogenetic with the Morro do Ferro rock
- Compilation, analysis, and modeling of water chemistry data that are now available on a routine basis.

WBS 1.3.7

PROJECT: Hydrology of Nearly Impermeable Rock

PRINCIPAL INVESTIGATOR: Lawrence Berkeley Laboratory (C. Wilson, T. Doe, and J. Long)

ONWI PROJECT MANAGER: M. R. Wigley

OBJECTIVE

The objective of the well test design task is to develop improved well test techniques for low-permeability rocks by (1) testing the constant head (pressure) injection, and (2) developing transient flow-rate solutions for the constant head test for a variety of flow-path geometries. These can be used to generate probability density parameters of functions for fracture geometry, which in turn can be used as input to stochastic flow models and hydrologic transport risk analyses.

The objectives of the study of regional fracture parameters are to determine when a fractured rock system may be treated as an equivalent homogeneous, anisotropic porous medium, and what values of equivalent porous media properties apply to such systems.

PROGRESS REPORTED PREVIOUSLY

Analytical solutions for constant head, transient flow-rate injection tests on single fractures were prepared for a variety of open and closed boundary conditions. In addition, solutions were prepared which include fracture deformation using coupled stress-flow numerical codes, showing that fracture deformation alters the shape of the transient flow-rate curve one would expect in well testing. This alteration affects the interpretation of permeability and storativity.

Following FY 80 completion of a literature survey of fracture parameters, a numerical fracture system model was adopted and coupled to a fluid flow program for numerical permeability testing.

A parameter study, performed to provide a framework for further sensitivity analysis, showed how changes in system parameters individually affect the hydraulic performance of fracture systems. In these studies density, aperture distribution, orientation distribution, and mesh size were varied. Increases in fracture density, uniformity of aperture distribution, and nonuniformity of orientation distribution all caused the fracture systems to behave more like porous media. Increasing the mesh size showed that, although a small volume may behave hydraulically like a porous medium, such behavior is not necessarily representative of the entire rock mass.

ACTIVITIES DURING THE REPORTING PERIOD

A major goal of the nearly impermeable rocks program is to determine if the hydraulically effective size and shape of fractures can be determined from well tests. Such data are required to predict ground-water flow rates from statistical data of the fracture system geometry.

To determine fracture size and area, 12 constant head injection tests were performed in an NX, 30-meter-deep well drilled into Sierra White granite. A two-packer system with a packer spacing of 0.6-meter was used to isolate the individual fractures on which the well tests were performed. A two-pressure transducer housing allows continuous monitoring of packer and injection zone pressures downhole. A pneumatic valve, located immediately above the packer system for opening or closing the packed-off zone of the hole to flow, allows application of the constant head to the test zone within about one second of the start of the test. A minicomputer system converts raw test data to engineering units, prints and stores all test data, and graphically displays log-log or semilog plots of flow rate versus time. The graphics display was especially helpful for deciding the length of tests.

In high flow-rate zones, tests were run using the turbine flowmeter manifold and injection heads of about 4 meters above the hydrostatic head. In tighter zones, the low flow-rate positive displacement meter was used, with injection heads as high as 50 meters to investigate fracture deformation effects.

Initial inspection of the data shows that some of the transient flow-rate curves from the tests follow the closed boundary-type curves initially, but deviate from the curves at a later time. Such behavior suggests a partially open fracture, that is, the presence of an intersection with another conducting fracture or some other open boundary. A numerical model of partially open fractures has caused numerical instability. The problem is not in the numerical model code, but in the geometry of the system. As a result, type curves for partially open fractures may be delayed.

In the regional fracture parameter task, the finite-element fracture flow program LINEL was modified. The solver in LINEL was replaced by one which stores the nodal information more efficiently. It should be possible to analyze fracture systems that are almost an order of magnitude larger than those previously handled. Further changes to the node numbering system will complement the change in the solver. These changes are now being debugged. The algorithm for finding the best fit permeability ellipse has been written and documented.

FUTURE ACTIVITIES

During the next quarter, analysis of the test data will continue, and a draft report on the analysis and procedures for constant head well testing in fractured rock will be written.

The debugging of LINEL will be completed. A final sensitivity problem will be run. The FY 81 report will be written.

WBS 1.3.7

PROJECT: Behavior of Natural Repositories

PRINCIPAL INVESTIGATOR: Los Alamos National Laboratory (D. B. Curtis)

ONWI PROJECT MANAGER: N. Hubbard

OBJECTIVE

The objectives of this study are (1) to develop an understanding of migration and retention of fission products and other radionuclides in natural repositories such as Oklo and rich uranium ore bodies, and (2) to relate their behavior to the performance of a mined geologic repository.

PROGRESS REPORTED PREVIOUSLY

The U.S. participation in the international investigation of the Oklo natural fission reactor phenomenon began in FY 75.

The Oklo phenomenon refers to the occurrence of self-sustaining fission chain reactions about 2×10^9 years ago in a series of very rich uranium ore pockets located in an extensive Precambrian pitchblende deposit in Gabon, Africa. Criticality lasted several hundred thousand years, and approximately 10 tons of uranium were fissioned. Many fission products were retained at the sites where they were generated. Other products from uranium decay or fission have been shown to be missing in whole or in part from the fossil reactor cores. The studies to date have examined the spatial, temporal, and chemical features of the processes that fractionated and redistributed the fission and radioactive decay products. A detailed study of reactor zone 9 (ORZ-9) has shown that neodymium has been retained in the reactor zone and ruthenium has been redistributed within the zone but not outside it. Significant quantities of ^{99}Tc and most of the fissiogenic molybdenum have been transported away from the materials which comprise ORZ-9.

Rocks taken from distances up to 45 meters from the ORZ-9 contain quantities of molybdenum that can account for the deficiencies within the zones. However, there is no evidence that ^{99}Tc has been retained in these peripheral rocks. Isotopic analyses show trace quantities of ^{234}U-depleted uranium in peripheral rocks. These observations demonstrate that small quantities of this element were transported from the reactor zone into surrounding rock.

Leaching studies on spent fuel rods pointed out the difficulty in making and maintaining solutions with low oxygen fugacities. Such low Eh conditions are considered to be representative of those found in many deep crustal rocks. The availability of such conditions is vital in attempting to characterize the chemical properties of repository materials in crustal environments. Recent efforts have developed procedures to produce, maintain, and characterize low-oxygen-fugacity solutions.

ACTIVITIES DURING THE REPORTING PERIOD

Two nuclides of concern to the management of waste storage are ^{137}Cs and and ^{90}Sr. These nuclides were abundant products of the nuclear activity at Oklo. Appropriately designed experiments can address the retention and transport of alkali and alkaline earth elements at the Oklo site. These experiments require high-precision mass spectrometric analyses on barium, strontium, and ruthenium separated from the Oklo rocks. The analyses will be done on the ORZ-9 materials and rocks peripheral to them, the same samples that were previously analyzed for abundances of fissiogenic molybdenum, ruthenium, neodymium, and uranium. Chemical procedures have been established at this laboratory to separate these elements from the rock matrix. The procedure is standard for this purpose and involves chromatographic separation of each of the elements on a cation exchange column. A mass spectrometric procedure for measuring barium isotopic ratios was developed and tested. Ten analyses of a standard barium solution produced the following results:

$^{138}Ba/^{137}Ba$ = 9.12856 ± 0.05 percent, $^{137}Ba/^{136}Ba$ = 1.42876 ± 0.05 percent, and $^{135}Ba/^{136}Ba$ = 0.83943 ± 0.03 percent. Normal barium isotopic ratios measured by a double-spike technique are highly accurate and used as standard values. The accuracy of the results was assessed by normalizing to these ratios. The results of these comparisons are as follows: $^{138}Ba/^{136}Ba$ = 0.99994, $^{137}Ba/^{136}Ba$ = 0.99994, $^{135}Ba/^{136}Ba$ = 1.00012. The magnitude of deviation from unity is a measure of the accuracy of the measurements. The mass spectrometric procedure is precise and accurate to the degree required for the analysis of the Oklo materials. Barium was separated from standard solutions by the ion exchange method and analyzed for isotopic ratios to see if the measurements were degraded by the chemical procedures. The results of five mass spectrometric measurements of the separated barium gave the following results: $^{138}Ba/^{136}Ba$ = 9.137 $\pm$ 0.05 percent, $^{137}Ba/^{136}Ba$ = 1.4288 $\pm$ 0.02 percent, and $^{135}Ba/^{136}Ba$ = 0.8394 $\pm$ 0.01 percent. These results, normalized to the unseparated analyses for barium, gave the following ratios: $^{138}Ba/^{136}Ba$ = 1.00094, $^{137}Ba/^{136}Ba$ = 1.0001, and $^{135}Ba/^{136}Ba$ = 0.99958. The interface between the chemical procedure and the mass spectrometer does not significantly degrade the quality of the measured ratios.

Additional experiments on the use of indigo carmine (indigo 5.5' disulphonic acid) in the potentiostat-controlled Eh cells have shown the following results:

1. A non-pH buffered system exhibits large pH changes during oxidation-reduction experiments.
2. Gel-filled electrodes are as accurate as solution-filled ones and far easier to use in an inert atmosphere glove box.
3. Although the experiments were conducted in an inert atmosphere glove box, there is still a slow oxidation of the reduced indigo carmine solution.
4. After reduction with potentials calculated to reduce 99.99 percent of the indigo carmine, the material is oxidized at a faster rate than that observed in the experiments described in no. 3 above.
5. Experimental Eh versus pH values for indigo carmine are ∿ 100 MV more negative than literature values.

FUTURE ACTIVITIES

The following activities are planned:

1. Analysis to determine lead-uranium dates on the Key Lake ores will be completed and the results integrated into the overall study of lead and uranium migration at Key Lake.
2. A paper will summarize the retention and transport of ruthenium and ^{99}Tc at the Oklo natural reactor.
3. Analyses for lead and uranium in samples from Oklo will be completed in an attempt to identify transport paths at distances of several hundred meters from the ores.
4. Analyses for isotopes of ruthenium and molybdenum in samples to the east of reactor zone 9 will be completed.
5. A topical report on the immobilization of uranium will be completed.

SUMMARY

1.4 REPOSITORY

The scope of the Repository Task covers the development of design specifications, preparation of a repository design data base, development of instrumentation and equipment, design and development of repository designs and repository seals, and performance evaluation of the repository with the total nuclear waste isolation system. The prime objective of the repository task is to develop suitable repository designs, including required instrumentation and equipment. Progress in various R&D areas is summarized below:

Salt Data Base

WBS 1.4.1

The Expected Repository Environments in Salt project was increased in scope to include the following tasks:

- Determine the sensitivity of near-field thermal environments in salt to advanced waste package design.
- Determine the dependence of salt thermal environments on realistic canister loadings and emplacement scenarios.
- Compare thermal environments for several media based upon common design bases.

To implement the first and second tasks, two-dimensional far-field models were developed to calculate temperature histories resulting from the emplacement of spent fuel (SF) and commercial high-level waste (CHLW) in salt according to realistic loading scenarios. The plan was to use these models to provide boundary conditions for near-field calculations.

WBS 1.4.2

There were two major activities this quarter in the Bench Scale Salt Creep Tests, Phase III: (1) the salt block for the first biaxial test No. 1, and (2) tensile tests on 7-1/2-inch-diameter salt specimens with strain gages bonded on one face and a photoelastic sheet bonded on the same face over the gases.

The studies of Transient Creep in Rock Salt involved a variety of activities this quarter, including:

- Experimental work on synthetic rock salt specimens deformed at 25 C and 0.1, 20, and 100 MPa.
- Observations of grain-boundary modifications in deformed specimens of synthetic rock salt.
- Bench testing the data acquisition system for the new large-specimen apparatus.
- Monitoring the construction of the new large-specimen apparatus.

The Salt Model Pillar Studies project tested a series of model pillars, fabricated from rock salt in the Wellington Formation, Kansas, in Rayburn's Dome, Louisiana, and in Cypress Creek Dome, Mississippi, at axial loads of 4,000 to 6,000 psi and at temperatures of 22.5 and 60 C. These tests were conducted to obtain data on the deformation of rock salt under temperature and pressure conditions that would be expected in an actual disposal operation. The results indicate that for each sample there is initially a high rate of deformation that decreases with time. This decrease in deformation rates is shown to continue to 600 hours. However, in longer duration model tests, it has been observed that rates continue to decrease even after several years. These results are in agreement with measurements that have been made in various salt mines.

The major thrust of the Strain-Related Radiation Damage studies is to determine the effects of irradiation over a range of temperatures in various host rocks to predict long-term radiation effects. Studies to determine which rock salt dislocations are likely sites for nucleating sodium metal colloid particles during irradiation have been completed, in the most useful elastic constant range, for the < 001> edge dislocation and are now being made for the < 111> edge dislocation.

The post-test evaluation of the Avery Island Sites A and B heater tests was continued during the quarter. Activities included the removal of the Site B heater and sleeve assemblies and continued data-gathering activities at both sites. Also, the Site NB (natural brine) brine movement experiment was terminated, the Site SB (synthetic brine) overcore was completed at a final depth of 19 feet 7 inches, and two of the Phase II accelerated borehole closure experiments were activated.

The major events during this quarter, for the Experiment Development to Support Field Testing, were issuance of the Final Test Plan for the brine migration test at Asse and completion of the preliminary design of the test hardware.

WBS 1.4.8

The Material Properties Testing and Analysis project completed the comparison and evaluation of the field-measured and numerically calculated temperatures, displacements, and stresses from the Site A heater test at Avery Island.

During the quarter the Convective Heat Transfer in Room and Pillar Geometries project has made significant progress in obtaining a correlation for fully developed Nusselt numbers in a rectangular duct with aspect ratio 1.0. Reynolds numbers ranged from 98,300 to 32,000. In addition, three regions were identified in the rectangular duct: laminar, transition, and fully developed turbulent flow. The thermal and hydrodynamic entry length has been determined for the above ranges of Reynolds numbers.

The Effects of Far-Field Inhomogeneities on Surface Temperature and Heat Transfer From a Repository are under investigation in both the experimental and analytical areas. Experimentally, a new model repository was designed and constructed. The previous model was limited by the fact that only one repository configuration could be tested. The new design permits more versatile geometrical configurations, and the dimensional properties of the system have been improved. Analytically, the two-layer, one-dimensional linear model of the repository has been analyzed. An important parameter of the present model is the fraction of heat passing above (or below) the repository.

Granite Data Base

WBS 1.4.2

The studies of Materials Properties and Stress Measurement Techniques have centered on a variety of activities as follows:

- Development and checkout of the software for computer control of the electroservo system was completed.
- A calibration test was performed using an aluminum sample of known properties.
- A series of tests comparing the Swedish deep-hole Leeman triaxial cell and hydrofracturing stress measurement techniques in borehole SBH-4 was completed.
- Final plans were made for the stress measurements, and a test plan was submitted to ONWI.

Investigations were conducted at Stripa in three core-drilled boreholes, one 1,000-meter-deep vertical hole (V1) and two 300-meter-long nearly horizontal holes (N1 and E1). During this quarter the Stripa testing project conducted no drilling in borehole V1 because the poor rock quality in the lower part of V1 (between 450 and 506 meters) makes it necessary to stabilize the borehole before continuing the drilling. The stabilization will, however, damage the zone and reduce the value of future hydraulic and hydrogeochemical investigations. It was therefore decided to wait as long as possible with the stabilization and focus the drilling operation on the two horizontal boreholes, both of which have been completed.

WBS 1.4.8

In the Stripa Data Analysis project, a work plan for data analysis was prepared that includes these primary components:

- Prepare refined estimates of hydraulic conductivity for the rock surrounding the ventilation drift.
- Compare the macromeasurement of this experiment to the University of Waterloo borehole measurements.
- Undertake two-dimensional discrete fracture modeling of rock around drift to identify parameters controlling water inflow and pressure distribution.
- Study possible causes of low permeability "skin" of rock around drift.
- Conduct miscellaneous studies.
- Prepare model of drift and rock mass to study parameters controlling water inflow and pressure distribution.

Both the application and the development of the thermohydromechanical fractured rock code ROCMAS were emphasized this quarter. Generic applications were made for thermomechanical deformations and for hydromechanical processes in fractured rocks. Also, the paper on the status of modeling was reviewed.

The main objective during this quarter of the Analysis of Flow Through Fractured Crystalline Rock was to develop the basic statistical parameters needed to characterize the fracture system at Stripa. This has included calculating the true strikes and dips of the fractures from the relative orientations of fractures mapped in the drill core.

In the Fractured Rock Studies Program, data reduction was completed for the first series of flow tests on the natural fracture in the 0.942-meter-diameter Charcoal Black Granite, and data reduction of the second series of flow tests in in progress.

Generic Repository Engineering

WBS 1.4.2

The project on Rock Behavior Under Elevated Pressure and Temperature centered on two major activities this quarter. Calibration of the thermal conductivity measurement has been achieved with the completion of the run on the reference standard of GE 124 fused silica. Data were taken to 50 MPa and 200 C, as planned. Also, permeability tests now under way in Units I and II on intact samples of Climax Stock quartz monzonite and Stripa granite are nearly completed.

WBS 1.4.6

The activities of the project on Alternative Geologic Media Engineering Studies this quarter included development of general design considerations for a radioactive waste repository in any potential host rock and initiation of the development of a data base of site and media characteristics for welded tuff and basalt rock types.

The report, Numerical Simulations of Earthquake Effects on Tunnels for Generic Nuclear Waste Repositories, by Science Applications, was completed. The objectives of this generic study were to use numerical modeling techniques to determine under what conditions seismic waves generated by an earthquake might cause instability to an underground opening, or cause fracturing and joint movement that would lead to an increase in the permeability of the rock mass.

Equipment and Instrumentation

WBS 1.4.3

The NWTS Repository Equipment Development Plan continued on three project tasks. The major activities included revision of the technology development plan for NWTS repository equipment, preparation of a draft repository equipment test plan, and preparation of draft Statements of Work for equipment technology developments.

WBS 1.4.4

The key technical activities this quarter on the Directional Antenna project covered two major areas. The first was characterization and modeling of the directional probe, and the second was determination of an optimum system and prediction of performance.

Repository Sealing

WBS 1.4.5

The Seal Materials Selection and Longevity program continued experiments and testing on cement-based materials, clay and clay composites, and zeolites to determine their feasibility for performing as seals in repository environments.

During this quarter the Seal Materials Performance Limits and Longevity project focused on five activities, including:

- Tests of four high-sulfate-resistant Class H cements were completed.
- Examinations of five laboratory grouts about 4 years old and of grouts from two Bell Canyon Test plugs were completed.
- Structures Laboratory Work Memorandum 81-21 on cracking in grout specimens during storage was issued identifying the conditions under which specimens crack in storage, and why.
- Tests of six plasters and one plaster retarder were made.
- Chemical dissolution tests of fly ashes were continued.

The results from the plug flow test have been analyzed and are in good agreement with the results obtained from the Bell Canyon borehole plug test. The dye penetrant added to the water during the flow test clearly indicated that the flow path was at the cement-rock interface.

WBS 1.4.1

PROJECT: ONWI Support Program: Program Coordination and Special Problems

PRINCIPAL INVESTIGATOR: Oak Ridge National Laboratory (T. H. Row, Coordinator)

ONWI PROJECT MANAGER: G. E. Raines

TASK 1: GENERAL ACTIVITIES
(S. H. Stow)

OBJECTIVE

The objective is to allow continuity in program planning and direction and to allow new or short-term projects to be undertaken.

PROGRESS REPORTED PREVIOUSLY

Previously work included research on sensitivity analysis, thermal analysis, analysis of a series of salt samples from the Asse Mine in the Federal Republic of Germany (FRG), preparation of a technical report on Material Considerations Relative to Multibarrier Waste Isolation, and program planning direction for the ORNL Waste Isolation Program.

ACTIVITIES DURING THE REPORTING PERIOD

This quarter's work has included the work noted above as well as the development of some new projects. Work on thermal analysis has continued and is reported as the following task.

The technical report, Material Considerations Relative to Multibarrier Waste Isolation, deals with environmental conditions associated with the storage of radioactive wastes and evaluates the corrosion potential of containment materials. The desired service life of 1000 years goes beyond the period for which existing corrosion data can be reliably extrapolated. Titanium alloys are the best choice. Mechanical requirements for canisters and overpacks are considered, and design considerations for canisters and overpacks are developed. Costs for three possible materials are estimated.

Chemical analyses of the 12 salt-core samples of the Asse Mine in the FRG and of one salt-core sample from Richton Dome in the U.S. were completed except for analyses for certain cations in soluble portions of the samples.

A study of a system model to assess flooding of a salt repository will be undertaken. The model will allow evaluation of the expected behavior of a nuclear waste repository in salt after water intrusion and will provide the methodology to assess the consequences of flooding scenarios to be included in a safety analysis report for salt repositories. It will also provide the basic framework for similar analyses in hard rock repositories. Computer codes will be written and/or existing ones adopted as system components and these will be interfaced to produce the system behavior model.

A second new task will deal with uncertainty analysis and will emphasize determination of the suitability of the PROSE language for obtaining adjoint codes for sensitivity analysis related to deep geologic disposal of nuclear waste.

FUTURE ACTIVITIES

The technical report on material considerations will be published. Chemical analyses of the Asse salts will be completed. Development of the code parameters for the flooded repository model will be undertaken and will be reported at the end of the next quarter. An assessment will be made of the suitability of the PROSE language for sensitivity analysis.

TASK 2: THERMAL ANALYSIS

(H. C. Claiborne)

OBJECTIVE

A thermal analysis of the as-built configuration of the Avery Island thermal experiments was completed in 1978, and the results were reported internally. The results will be documented formally because these pre-experimental calculations are to be used in comparison with the experimental results and other calculations in the final report on the Avery Island experiments.

PROGRESS REPORTED PREVIOUSLY

The project was begun in November, 1980, and a draft report was prepared. A brief abstract of the report follows.

"This report documents the thermal analysis that was performed in support of the design effort of the three Avery Island field tests. The Avery Island experiments are simulated waste canisters to generate quantitative data to validate analytical predictions that use laboratory-measured properties and numerical models to simulate effects in the field. Results from the field tests will include the determination of the thermal conductivity of a field salt formation, temperatures and temperature gradients in the adjacent salt formation, and room and canister-hole deformations. This report furnishes the necessary documentation to compare these a priori calculations with experimental results from the Avery Island field tests, as well as time-temperature histories at selected points of interest."

ACTIVITIES DURING THE REPORTING PERIOD

The report has been published (Just, 1981).

FUTURE ACTIVITIES

No future activities are planned.

REFERENCE

Just, R. A., 1981. Thermal Analysis Supporting the Design of the Avery Island Field Experiments, ORNL/ENG/TM-31, Oak Ridge National Laboratory, Oak Ridge, TN, May.

WBS 1.4.1

PROJECT: Expected Repository Environments in Salt

PRINCIPAL INVESTIGATOR: Oak Ridge National Laboratory (H. C. Claiborne)

ONWI PROJECT MANAGER: G. E. Raines

OBJECTIVE

The primary objective is to provide information in designing experiments and repositories and in licensing procedures based on calculated expected repository environments for the disposal of both commercial and defense high-level wastes and spent fuel in salt formations. The predicted environments or effects include near-field and far-field temperature histories, brine chemistry, brine migration rates, fluid pressure histories, and nuclear radiation fields.

PROGRESS REPORTED PREVIOUSLY

This project began in March, 1979. The work on commercial high-level waste (CHLW) and spent fuel (SF) was completed and a final report issued (Claiborne, Rickertsen, and Graham, 1980).

The work on defense high-level waste (DHLW) was also completed and a final report issued (Rickertsen and Claiborne, 1981).

ACTIVITIES DURING THE REPORTING PERIOD

The project was increased in scope to include the following tasks:

1. Determine the sensitivity of near-field thermal environments in salt to advanced waste package design.
2. Determine the dependence of salt thermal environments on realistic canister loadings and emplacement scenarios.
3. Compare thermal environments for several media based upon common design bases.

In implementing the first and second tasks, two-dimensional far-field models were developed to calculate temperature histories resulting from the emplacement of SF and CHLW in salt according to realistic loading scenarios. The plan was to use these models to provide boundary conditions for near-field calculations.

Scoping calculations involving a limited parametric analysis were then made for these models. Unfortunately, the results demonstrated that the simple near-field and far-field models used did not represent the system temperatures adequately. The primary reason for the effect is the strong temperature dependence of the salt conductivity at the relatively low temperatures involved (even for high-level waste), and the resulting nonlinearity of the system invalidates the use of decoupled near- and far-field models. Consequently, a new model was developed that simultaneously treats the near- and far-field features. This combined model is extremely large and costly to run, which may limit the number of calculations that can be made.

The initial case for sequential loading of SF in a southern regional repository located in a salt dome is being prepared. The repository is 8.5×10^6 m^2 (2100 acres) in size. Emplacement will begin in the year 2000 and end in 2056. A similar sequential loading model will be prepared for a national repository.

Modeling has also been initiated for the internal temperatures in the advanced SF and DHLW packages. Designs are being prepared by Westinghouse. The very near-field models for canister surface temperatures for both SF and DHLW were completed. For the SF cases, the surface temperatures will be used as boundary conditions for the HYDRA-I code calculations (includes conductive, convective, and radiative heat transfer) of the SF pin temperatures. Standard thermal conduction modeling will be used for the DHLW glass matrix temperature. For the first calculations, six waste package cases have been prepared: five SF and one DHLW. The SF cases include both the borehole and the self-shielded concepts, whereas the DHLW case is only for the borehole concept.

FUTURE ACTIVITIES

The work on the new tasks will be completed and a draft report issued.

REFERENCES

Claiborne, H. C., L. D. Rickertsen, and R. F. Graham, 1980. Expected Environments in High-Level Nuclear Waste and Spent Fuel Repositories in Salt, ORNL/TM-7201, Oak Ridge National Laboratory, Oak Ridge, TN, August.

Rickertsen, L. D., and H. C. Claiborne, 1981. Expected Environments for a Defense High-Level Waste Repository in Salt, ORNL/TM-7597, Oak Ridge National Laboratory, Oak Ridge, TN, March.

WBS 1.4.1

PROJECT: Expected Repository Environments in Granite (ERE-G)

PRINCIPAL INVESTIGATOR: RE/SPEC, Inc. (J. D. Osnes)

ONWI PROJECT MANAGER: G. E. Raines

OBJECTIVE

The objective of this study is to establish the expected repository environments in a generic granitic repository containing commercial high-level waste, defense high-level waste, or spent fuel. The expected repository environments will be described in terms of transient temperature fields, deformations, resultant stress states and regions of strength failure, and perturbations to ground-water flow. In addition to these states or environments, consideration will be given to describing chemical and nuclear radiation environments and vapor pressures in the waste package drillholes and in the disposal rooms.

This work supports and addresses particular problems relative to the Rock Mechanics Program of the NWTS program. In particular, the ERE-G study provides technical bases for reports authored by the Reference Repository Conditions Interface Working Group (RRC-IWG), an ad hoc IWG established by the Isolation Interface Control Board.

PROGRESS REPORTED PREVIOUSLY

A report on interim reference repository conditions for commercial and defense HLW and SF repositories in granite was drafted in support of the RRC-IWG.

Based on geologic factors, major granitic formations in the United States were examined to determine their tectonics of formation and rock mass properties, including joint characterization and in situ stress state.

ACTIVITIES DURING THE REPORTING PERIOD

During the quarter, Savannah River Laboratory provided an updated characterization of the thermal power of defense high-level waste (DHLW) as a function of time. These decay characteristics were used as input to a very near-field model of a DHLW repository in granite. The model was based on the reference repository characteristics with the exception that moist, crushed granite with a thermal conductivity of 1.0 W/mK was assumed. The pitch, and consequently the areal thermal loading, were varied to obtain the nomograph shown in Figure 1. This nomograph shows the peak canister surface temperature as a function of pitch for a 256 W canister. As long as the decay characteristics are not changed, this nomograph may be used to approximate the maximum surface temperature for a specified areal and canister thermal loading. For example, for an areal thermal loading of 6 W/m^2 and a canister thermal loading of 225 W, a pitch of 2.5 m is required. This pitch is obtained from the following equation:

$$P = \frac{n_{row} \times CTL}{W \times ATL} ,$$

where

P = pitch

n_{row} = number of rows of canisters (2)

CTL = canister thermal loading

W = centerline-to-centerline distance between rooms (30 m)

ATL = areal thermal loading.

From Figure 1, a peak surface temperature of 75 C is obtained for a pitch of 2.5 m. However, this temperature is for a canister thermal loading of 256 W. The following equation may be used to adjust the temperature for a canister thermal loading other than 256 W:

$$T = \frac{CTL}{256} \times \ (T^* - T_{amb}) + T_{amb},$$

where

T = peak canister surface temperature (C)

CTL = canister thermal loading (W/m^2)

T^* = peak canister surface temperature for CTL = 256 W/m^2 (C)

T_{amb} = ambient temperature (20 C).

Consequently, for an areal thermal loading of 6 W/m^2 and a canister thermal loading of 225 W, a peak temperature of 68 C is expected on the surface of a DHLW canister in granite.

Modeling of the far-field thermomechanical environment was initiated, but is at too early a stage to report significant technical results.

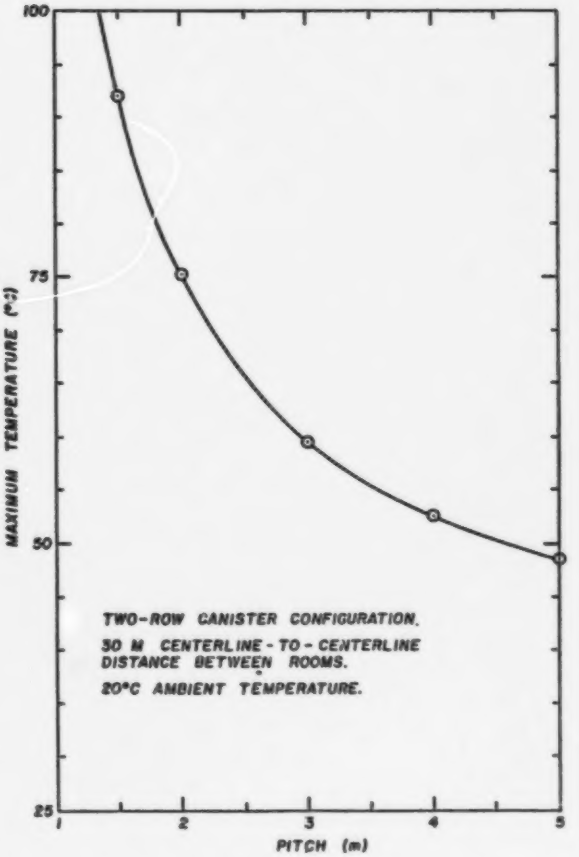

Figure 1. Maximum Canister Surface Temperatures for a 256 W DHLW Canister in Granite with Moist Backfill.

FUTURE ACTIVITIES

The near-field and far-field thermomechanical environments will be predicted during the next quarter. Also, the effect of blast cooling on the near-field thermal environments will be examined.

WBS 1.4.2

PROJECT: ONWI Support Program: Thermal Property Measurements

PRINCIPAL INVESTIGATOR: Oak Ridge National Laboratory (J. G. Moore and M. T. Morgan)

ONWI PROJECT MANAGER: M. M. Lemcoe

OBJECTIVE

The objective of this program is to obtain accurate thermal data to be used in thermal analysis of possible repository sites. Methods and procedures will be established for making thermal property measurements, and data will be obtained on selected specimens of cores from possible repository sites and standard natural materials.

PROGRESS REPORTED PREVIOUSLY

The program began in 1977. Thermal conductivity measurements of rock salt were reported in ORNL/TM-6809(4) and of other rocks in ORNL/TM-7052(6). More recent measurements were taken of Cypress Creek rock salt and caprock. These determinations showed a significant difference between the results obtained by ORNL and those by the Energy Materials Testing Laboratory (EMTL) of Fiber Materials, Inc. Further investigations on Pyroceram 9606 reference material revealed that approximately half of the difference in the results could be attributed to a difference in the values used for the Pyroceram 9606. EMTL used values derived from diffusivity measurements, while ORNL used values from the NBS data series which were obtained by steady state radial heat flow measurements.

Efforts to develop a means of measuring the thermal conductivity of friable materials resulted in the development of a thermal conductivity cell which has been tested with glass fragments. Many coatings and films were tested for improving the thermal contact in thermal conductivity measurements. Metal foils and graphite cloth were shown to be ineffective at low pressures. The metals tested did not include indium foil, which may be applicable but is too expensive for routine use.

During the previous quarter, additional coating formulations containing aluminum powder in vehicles of varnish and water glass were tested, but the combined goals of high thermal conductivity, adherence to salt and other rocks, and low enough viscosity for application were not achieved. Pulsed laser diffusivity data from EMTL and the literature on Pyroceram 9606 were compared and showed good agreement.

ACTIVITIES DURING THE REPORTING PERIOD

Research continued on developing a coating to improve the thermal contact at interface surfaces for thermal conductivity measurements. A friable salt sample, previously measured for thermal conductivity by the usual cut bar method, had been roughly cut and eroded in a thermal conductivity cell experiment which failed. This treatment produced a specimen having a rough upper surface with pits up to 1 mm in depth covering 20 percent of the surface--ideal for testing a thermally conductive coating.

Thermocouples were placed in grooves in the center of the upper and lower surfaces, and the rough upper surface was coated with 90 percent aluminum-filled epoxy. The thermal conductivity of the epoxy was estimated to be $\sim$1.8 W/m·K at 373 K, approximately half that of salt. The coating was cured, and the sample was finished to flat, parallel surfaces for thermal conductivity measurements. The thermal conductivities ranged from 3 to 5 percent lower than those by the previous measurement over a temperature range from 310 to 540 K. The application of the coating was difficult, however. The coating was too viscous, stiffened rapidly during application, and left voids in the surface which had to be filled with a second application.

Additional coating formulations were tested. Adding salt and lime to the basic 90 percent aluminum-filled water glass preparation increased the working time and the adherence to salt. However, the thermal conductivity varied drastically between 1 and 5 W/m·K, with minor changes in composition and mixing procedure. Application was made easier by placing a uniform layer of the mix on aluminum foil and then pressing the layer and foil against the absorbent sample surface. A special press with polished, parallel plates was constructed for this purpose so that the finished surfaces would be flat and parallel.

Efforts continued to improve the accuracy of thermal conductivity measurements on rocks. Data from thermal conductivity measurements on salt by various installations have been fitted to equations of the form

$$\lambda = AT^B,$$

where T is in degrees K. Table 1 compares the results, which show a range of thermal conductivity for rock salt of from 2.0 to 5.1 W/m·K at 373 K. Measurements by EMTL, Dynatech, and ORNL were made using comparative steady state heat flow instruments with Pyroceram 9606 as a reference. In previous reports, it was pointed out that a difference of about 10 percent existed in the thermal conductivities reported for Pyroceram by the absolute steady state heat flow methods and those calculated from thermal diffusivities obtained by pulsed laser measurement. The thermal conductivities for salt have been calculated using both sets of data for Pyroceram. Those calculated using the NBS steady state method data (1) are in closer agreement with measurements reported by Sweet (2) and Yang (3).

FUTURE ACTIVITIES

Plans will be completed for modifying the Dynatech instrument to make absolute thermal conductivity measurements. Reference materials for the comparative method standard will be obtained for testing. These will include Pyroceram 9606 from other sources. Thermal conductivities of fused quartz and single-crystal sodium chloride will be measured.

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Table 1. Thermal Conductivity of Rock Salt and Caprock.

Ref.	Source	Number of Samples[c]	Density, g/cc	Thermal Conductivity[a] λ, (W/m·K)			Coefficients[b] for $\lambda = AT^B$	
				NBS	Diff.	Other	A	B
Salt								
4	ORNL Avery Island	8	2.12	3.58	3.27		165	-1.04
	Jefferson Island	2		3.53	3.22		108	-9.966
	Cypress C (1701')	1	2.21	4.34	3.96		823	-1.27
5	EMTL Cypress C (1701')	1	2.21	3.78	3.44		530	-0.850
	Cypress Creek	3	2.21	3.76	3.43		966	-0.952
	Randall Cty.	3	2.16	3.78	3.45		1,296	-1.00
	Swisher Cty.	2	2.18	3.68	3.35		958	-0.955
	Vacherie Dome	1	2.18	4.53	4.13		151	-1.39
2	Dynatech	9		3.90	3.56		3,333	-1.14
2	Sandia & LANL	6				4.68	4,000	-1.14
3	NBS (Yang)					5.12	4,092	-1.13
Caprock (Cypress Creek)								
5	EMTL	1	2.96	3.84	3.50		2,719	-1.12
	ORNL (Preheat)	1	2.96	4.53	4.13		20,301	-1.42
	ORNL (Postheat)			4.11	3.75		3,973	-1.16

(a) Values obtained by comparative measurements are calculated based on both steady state (NBS) Pyroceram data and Pyroceram data from thermal diffusivity measurements (Diff.).

(b) Dynatech and ORNL used NBS steady state Pyroceram data for these measurements. Conversions were made by multiplying by factor 0.9689 exp(-22.5/T). EMTL used diffusivity-based data. Conversions were made by multiplying by factor 1.032 exp (22.5/T).

Sandia used a linear steady state heat flow conductivity system with a heat flow transducer. LANL used a heat probe which is a line source transient heat flow method.

Yang derived recommended values from several experiments, including Russian experiments, and concluded that values above 100 K were accurate to within 5 percent.

(c) Number of samples measured.

WBS 1.4.2

PROJECT: Bench Scale Salt Creep Tests, Phase III

PRINCIPAL INVESTIGATOR: South Dakota School of Mines and Technology (C. A. Kliche)

ONWI PROJECT MANAGER: M. M. Lemcoe

OBJECTIVE

The objective of this program is to provide bench scale, time-dependent deformation data on dome rock salt. These data will be used by other research groups to check existing computer codes on models that predict stress-induced deformation.

A method for measuring deformation of rock salt using photoelastic stress-strain measuring techniques and brittle coating techniques is to be developed.

PROGRESS REPORTED PREVIOUSLY

Bench Scale Testing

This task started in July 1979. The following activities were reported previously:

- Bench scale, uniaxial creep testing of dome salt at ambient temperature was completed, and a report was written.
- Stress-strain measurements were performed on laboratory scale dome rock salt specimens, and a report was written.
- A biaxial load frame was designed, fabricated, and tested.
- A cube of salt for the biaxial test, approximately 32.5 inches on each side, was received. A smooth finish was applied to the block, and an 8-inch-diameter hole was drilled through it.

Photoelastic Testing

The photoelastic phase of the project began in January 1981. Progress reported previously includes the following items:

- A machine for creep testing of laboratory scale specimens was fabricated.
- A test was done to observe the continuity of fringes across the splice between two separate sheets of photoelastic material bonded on salt. The results showed that the splice did not cause a problem.

ACTIVITIES DURING THE REPORTING PERIOD

Bench Scale Biaxial Testing

Finishing of the salt block for the first biaxial test No. 1 was completed.

An investigation into the possible cause of dissymmetry in the four quadrants of the fourth uniaxial test was conducted. The investigation was done to assure that the same problem does not appear in the first biaxial test. It was determined from the investigation that:

1. No errors existed in the computer data reduction code.
2. Loading of the block was symmetrical.
3. Inaccurate measurements between closure measurement stations most likely contributed to the error.
4. Single crystal movement also may have contributed to the error.

The new flatjacks fabricated for the first biaxial test were pressure-tested during the reporting period. The intent was to test the flatjacks for leaks by confining them in the load frame and raising the pressure in them by 200 psi increments to 1000 psi. The intended procedure was not necessary since they are leaked at 200 psi. They are being repaired.

Photoelastic Testing

During this quarter, tensile tests were conducted on a 7-1/2-inch-diameter salt specimens with strain gages bonded on one face and a photoelastic sheet bonded on the same face over the gages. The tests were made to see if the gages, terminals, and wires seriously influenced the photoelastic fringes. Results show that the fringes were interrupted over the terminals and the wires. The horizontal and vertical strain as a function of radial distance was calculated from the photoelastic data and plotted in terms of the modulus of elasticity and Poisson's ratio. The computed strain was compared to the measured strain from the gages.

Uniaxial compression tests were conducted on a 4 x 4-3/4 x 10-inch salt specimen. A photoelastic sheet was bonded on one of the 10-inch-long sides, and strain gages ranging in length from 1/16 inch to 4 inches were bonded on the remaining three sides. Two measurement closure stations were also attached to each of the sides with the strain gages. The modulus of elasticity calculated from the mechanical gage data ranged from 1.0 x 10^6 psi to 2.25 x 10^6 psi, whereas the electrical strain gage data gave results of between 7.0 x 10^6 psi and 8.0 x 10^6 psi.

FUTURE ACTIVITIES

For the biaxial test, once the flatjacks are tested and found not to leak, instrumentation of the block will begin. The block will be placed in the load frame, and strain gages and closure measurement stations will be attached to the block. Finally, the instrumentation will be tested and, if no problems occur, the biaxial test will begin.

Compression tests will be conducted on two samples to accurately determine Poisson's ratio and the modulus of elasticity for the dome rock salt. The first test will be conducted on a 6-inch-diameter by 12-inch-long cylinder, and the second test will be on a 4-inch-diameter by 12-inch-long cylinder. Each sample will be instrumented with 6-inch-long strain gages to meet ASTM testing specifications of 10 times the grain size for strain gage length.

WBS 1.4.2

PROJECT: Transient Creep in Rock Salt

PRINCIPAL INVESTIGATOR: Texas A&M Research Foundation (J. Handin)

ONWI PROJECT MANAGER: M. M. Lemcoe

OBJECTIVE

The objectives are to (1) develop a transient creep constitutive relation for rock salt based on operative deformation mechanisms; (2) measure, experimentally, the state variables required for evaluating transient creep theories; and (3) determine the deformation mechanisms during transient and steady-state creep of rock salt.

PROGRESS REPORTED PREVIOUSLY

These tasks have been performed: (1) constant strain rate tests on warm-pressed, synthetic aggregates of pure halite at $10^{-4}s^{-1}$ at 100, 200, and 300 C and at confining pressures of 50, 100, and 200 MPa, and tests of homogeneous mixtures of halite and anhydrites at $10^{-4}s^{-1}$ at 200 C and confining pressures of 10, 100, and 200 MPa; (2) development of one- and two-mechanism fits to the experimental data; and (3) observational work on the structural characterization of experimentally deformed synthetic aggregates and natural rock salt specimens from WIPP.

Data gathered for the constant strain rate tests on synthetic material at 20 MPa confining pressure (at 100, 200, and 300 C) confirmed that, at these pressures and temperatures, the influence of confining pressure on strength is negligible. Temperature is by far the more important variable. In addition, deformation mechanisms also appear to be independent of these same confining pressures and probably also of the temperatures.

The quasi-steady-state strength of rock salt (differential stress at 10 percent shortening) is essentially independent of confining pressure over the interval of 5 to 200 MPa and temperatures from 25 to 300 C. Temperature is by far the most controlling factor. Comparisons of the test results on fine-grained, pure, synthetic aggregates with those of other workers on specimens of natural rock salt show that the mechanical properties and behavior of rock salt, down to the level of the dislocation, are independent of significant differences in grain size, minor impurities, and previous deformational history. The relationship between subgrain size and quasi-steady-state stress based on deformation of the synthetic specimen is very similar to that for experimentally deformed natural rock salt specimens. Subgrain size in deformed rock salt does not change during stress-relaxation tests, at least to 1800 s. The last two statements suggest that it should be possible to monitor stress changes due to excavation and/or thermomechanical sources in underground salt bodies by measuring the subgrain size at various localities in the rock mass.

ACTIVITIES DURING THE REPORTING PERIOD

The following activities took place:

1. Revision of the QA statement
2. Experimental and observational work on synthetic rock salt specimens deformed at 25 C and 0.1, 20, and 100 MPa
3. Observations of grain-boundary modifications in deformed specimens of the synthetic rock salt
4. Study of constitutive equations, with preparation of a topical report
5. Bench testing the data acquisition system for the new large-specimen apparatus
6. Monitoring the construction of the new large-specimen apparatus.

Room Temperature Tests

Six experiments were conducted on synthetic specimens at 25 C and confining pressures of 0.1 (three tests), 20 (two tests), and 100 MPa (one test). The stress-shortening curves show pronounced postyielding work hardening (from 2 to 5 to 8 percent shortening), followed by pronounced work softening in four tests at >5 to 8 percent shortening. Four of the six tests show strengths at 7 percent shortening that are ±7 percent of the mean (28 MPa); the other two specimens poorly reproduce these results. Particularly poor is the reproducibility at the lower confining pressures, as expected. Thin-section study of the room-temperature specimens at the three confining pressures indicates (1) intragranular fluid inclusions are not modified over those in starting materials, (2) there is some (10 to 20 percent) polygonization that increases with increasing confining pressure, and (3) the specimens at 0 to 20 MPa confining pressure exhibit conspicuous microcracking and grain-boundary cracking.

Grain-Boundary Modifications

In synthetic and naturally occurring rock salt, changes in bubble-tube connectivity and alignment resulted from deformation, but these changes were unable to be expressed quantitatively. In fact, very few changes in bubble density, bubble size, or tube length had been measured. During this quarter a scheme was devised to assess the relative degree of alignment (anisotropy) in the arrays of grain-boundary bubbles and tubes. One-hundred grain boundaries in each of 27 thin sections were characterized as exhibiting arrays having (1) random orientation (within the plane of the grain boundary), (2) one set moderately aligned, (3) two sets (usually at right angles) moderately aligned, (4) a single set strongly aligned, (5) a single set strongly aligned and another set moderately so, and (6) two sets strongly aligned (usually at right angles to each other). While these data are not yet fully evaluated, it is clear that alignment (anisotropy of the two-dimensional arrays) tends to increase in specimens stress-relaxed at 200 and 300 C, as compared to nonstress-relaxed sister specimens. At 100 C there is no such tendency.

Constitutive Equations

Fits of the transient stress equations to higher confining pressure (20 to 200 MPa) and higher temperature (100 to 300 C) data have been completed, showing results consistent with those given previously. The transient-deformation results are being compared with those of others in a draft report. The preliminary results of the stress-relaxation tests will also be reported.

FUTURE ACTIVITIES

During the forthcoming quarter, the following activities are planned:

1. Calibrate and put into operation the new large-specimen apparatus
2. Continue the observational work on subgrain size versus stress, deformation mechanisms, and grain-boundary modifications.

WBS 1.4.2

PROJECT: Salt Model Pillar Studies

PRINCIPAL INVESTIGATOR: Oak Ridge National Laboratory (T. F. Lomenick)

ONWI PROJECT MANAGER: M. M. Lemcoe

OBJECTIVE

The objective of this work is to provide data for the proper design of excavated cavities in rock salt repositories that are candidates for the storage and disposal of radioactive wastes.

PROGRESS REPORTED PREVIOUSLY

This project started at the beginning of FY 81. Short-term test data on model pillars of rock salt from the Rayburn's and Cypress Creek Domes, as well as from the Wellington Formation, have been reported in previous quarterly progress reports.

ACTIVITIES DURING THE REPORTING PERIOD

In order to obtain data on the deformation of rock salt under temperature and pressure conditions that would be expected in an actual disposal operation, a series of model pillars, fabricated from rock salt in the Wellington Formation, Kansas, in Rayburn's Dome, Louisiana, and in Cypress Creek Dome, Mississippi, were tested at axial loads of 4,000 to 6,000 psi and at temperatures of 22.5 and 60 C. The results of these tests are summarized in Table 1.

For each sample there is initially a high rate of deformation that decreases with time. This decrease in deformation rates is shown to continue to 600 hours. However, in longer duration model tests, it has been observed that rates continue to decrease even after several years. It should be added here, too, that this is in agreement with measurements that have been made in various salt mines. This decrease in the rates of deformation with time is illustrated in Table 1 where it is noted that, for the Rayburn's Dome test at 22.5 C and 4,000 psi, pillar shortening had reached about 1.70 percent for the first 100 hours but had only increased to 1.90 percent for the next 90 hours.

Perhaps the most impressive feature of the data in Table 1 is the occurrence of greatly accelerated deformations at elevated temperatures. In general, there is initially a high creep rate that decreases with time, as in the case with models tested at room temperature. For the tests at 6,000 psi and 60 C, pillar shortening progresses to about 15 percent after only 500 hours of testing. In general, cavity closure is complete after about 50 percent of pillar shortening in models deformed at elevated temperatures. This is due to the lateral flowage of salt into the room opening from the pillar, as well as the more or less vertical movement into the opening from the roof and floor. Indeed, this illustrates that exceedingly large deformations occur in relatively short periods of time, even at temperatures of 60 C. The model tests thus confirm the belief that closure rates for actual mine openings will be greatly accelerated with the addition of radioactive waste, which will increase the temperature of the salt.

The generic testing program milestone was completed, and a report was prepared discussing the findings during the quarter.

FUTURE ACTIVITIES

A decision on site-specific work will be made early in the next quarter.

Table 1. Summary of Data on Model Pillar Tests.

Pillar Shortening					
Time, hr	Cypress Creek Dome (MS), percent	Time, hr	Rayburn's Dome (LA), percent	Time, hr	Wellington Formation (KS), percent
		a. Test at 4,000 psi and 22.5 C			
1	0.49	1	0.55	1	0.39
10	1.02	10	0.97	9	0.83
96	1.61	100	1.70	102	1.66
196	2.25	190	1.90	195	2.30
311	2.39	265	2.15	310	2.50
407	2.81	406	2.43	406	2.99
527	3.12	502	2.53	526	3.32
647	3.22	605	2.73	646	3.60
		b. Test at 6,000 psi and 60 C			
1	2.32	1	2.43	1	3.33
10	4.78	10	4.88	10	6.18
99	9.20	98.5	8.77	82	9.33
200	11.38	100	10.97	199	11.88
318	13.28	309	11.98	295	13.33
406	14.70	390	13.17	391	14.70
502	15.63	510	14.05	478	15.23

WBS 1.4.2

PROJECT: Strain-Related Radiation Damage Measurements in Rock Salt for Waste Disposal Applications

PRINCIPAL INVESTIGATOR: Brookhaven National Laboratory (P. W. Levy)

ONWI PROJECT MANAGER: W. F. Ubbes

OBJECTIVE

Nuclear radiation from radioactive waste will subject the surrounding rock to exposures ranging from the negligibly small to those producing pronounced radiation effects, particularly in rock salt. The current project has two principal objectives.

The first is to determine radiation damage in rock salt in sufficient detail to estimate the damage produced at any point in a repository as a function of rock salt type, impurity levels, water content, exposure to radiation including total dose and dose rate effects, temperature vs. time profiles and related annealing effects, rock salt strain occurring prior to and after emplacement, etc.; in addition, determine the damage formation and annealing kinetics in sufficient detail to reasonably reliably extrapolate the laboratory data to the very long times, the temperatures, the strain rates, etc., occurring in an actual repository.

The second objective is to characterize radiation damage effects in granite, basalt, tuff, shales, clays buffer materials, etc., particularly under repository conditions. Unfortunately, very little radiation damage information is available on these materials. Also, the techniques which have provided so much useful damage data on rock salt, which is transparent, are not useful for opaque or translucent minerals. Consequently, roughly 40 percent of the current effort is devoted to the development of techniques for studying radiation damage, on the atomic defect and/or crystal lattice level, in opaque minerals. Under test are previously used methods and raw techniques such as photoacoustic spectroscopy.

PROGRESS REPORTED PREVIOUSLY

As a result of recent studies, a number of the most important radiation damage processes in both natural and synthetic rock salt are now reasonably well understood. Among these are dependence on temperature, total dose, and preirradiation strain. Less well understood are the differences between natural and synthetic salt and the role of impurities in damage formation. Two important aspects not understood are dose rate effects and the role of strain applied during and/or after irradiation.

Perhaps the most important radiation damage effect in rock salt is the formation of colloidal sodium metal particles during irradiation. In unstrained or slightly strained salt the colloid formation follows a classical nucleation and growth curve. The zero or low-growth-rate nucleation period extends to 10^6 or 10^7 rad. The rapid growth regime extends to the 10^9 rad or more and is well described by $C(t) = (\text{constant})\ (\text{time})^n$ or $C(t) = (\text{constant})\ (\text{dose})^n$ relations. The constants and the values of n differ greatly for natural and synthetic salt and depend strongly on strain and other factors. The colloid growth rate is negligible at 100 C, increases with temperature to a strong maximum at 150 to 175 C, and then decreases to a negligible level at 300 C. Most importantly, the colloid formation nucleation period is reduced by straining prior to irradiation; it is near zero for strains of 10 percent or more. At the moment the colloid concentrations expected in an actual repository are difficult to estimate, but they could be in the 0.001 to 0.1 percent range.

Radiation damage, particularly colloid formation, has been studied in natural rock salt from a large number of localities, including the WIPP site and Asse, FRG, and in different horizons at the same site. Variations in colloid levels of 30 or more are observed.

Details and additional studies are described in numerous ONWI Quarterly Reports and in publications. A recent paper is by Levy, Swyler, and Klaffky (1980).

ACTIVITIES DURING THE REPORTING PERIOD

Temperature Dependence of the Radiation-Induced F-Center Formation in Natural Rock Salt from Drillhole AEC-8 at the WIPP Site

Preliminary measurements on the temperature dependence of the radiation-induced F-center formation in salt from the 810 m level at the WIPP site were previously reported. Additional measurements are now largely completed, and the new results are shown in Figure 1. To reiterate, at any temperature the F-center versus dose (or irradiation) curve rises monotonically to a well-defined plateau. The plateau level, C_F^{sat}, is high at 100 C and decreases monotonically with temperature until it is negligible above roughly 300 C. The saturation level is an important parameter. From it one determines the F-center diffusion constant activation energy, which in a sense controls the colloid formation rate. According to Jain-Lidiard theory, an Arrhenius plot for C_F^{sat} should have a slope equal to $1/2E_f$, where E_F is the activation energy for F-center diffusion. The Arrhenius plot, Figure 1, contains a best-fit line, computed from the measured points between 117 and 253 C, which corresponds to a value of $E_F = 0.66$ eV. This should be compared to the 0.8 eV value used by Jain and Lidiard. Also, Figure 1 differs markedly from the corresponding plot for synthetic NaCl. The latter contains two distinct components corresponding to E_F values of 0.4 and 1.8 eV for temperatures below and above 250 C. The point at 275 C (1000/T = 1.82) has been excluded from the E_F determination since it is subject to large experimental error and lies more than three standard deviations from the curve shown. If it is included, E_F changes from 0.66 to 0.74 eV. However, the data versus fitted line correlation coefficient squared changes from 0.96 to 0.93. As mentioned previously, the Jain-Lidiard theory appears to describe radiation-induced colloid formation in natural salt better than in synthetic salt.

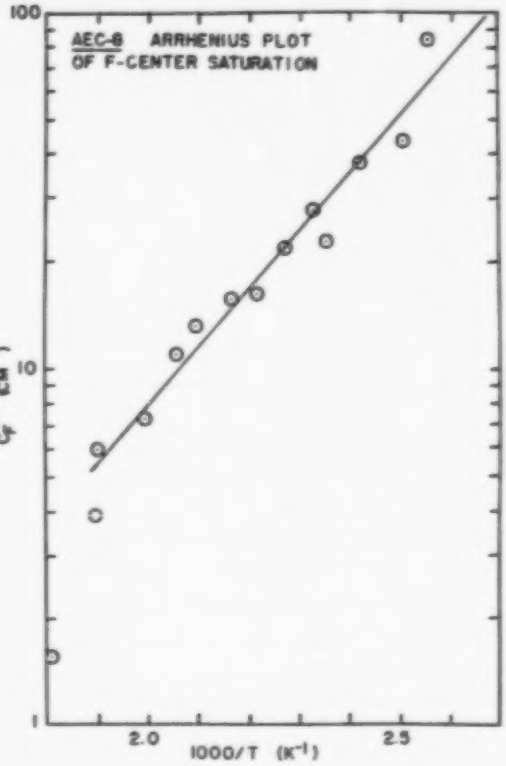


Figure 1. An Arrhenius Plot for Natural Rock Salt Samples from Drillhole AEC-8 (810 m level) at the WIPP Site. (The parameter C_F ^{sat} is the saturation level for F-center growth curves obtained by irradiating samples at the indicated 1000/T points. According to Jain-Lidiard theory the slope is equal to $E_F/2$, where E_F is the activation energy for F-center diffusion. In a sense, the F-center diffusion controls the radiation-induced colloid formation. The value obtained from the best-fit line on the plot is 0.66 eV. This plot differs markedly from a similar plot for synthetic rock salt. The latter contains two components which correspond to E_F = 0.4 and 1.8 eV.)

Gas Evolution from Rock Salt and Other Minerals Before, During, and After Irradiation

Colloid sodium metal particles form in natural and synthetic rock salt during and after irradiation. The formation rate is a function of dose, dose rate, temperature, strain in the samples, and several other variables. At large doses, for each sodium atom in colloid particles, a chlorine atom is formed. For both repository engineering needs, and to determine the basic radiation damage processes in rock salt, it is essential to determine if the chlorine remains trapped in the rock salt or diffuses out of the crystal as chlorine gas. To study this problem a temperature-controlled irradiation chamber has been fitted to a mass spectrometer-type gas analyzer.

Radiation Damage Studies on Opaque and Translucent Minerals

As part of the program to develop techniques for studying radiation damage on the atomic defect and crystal lattice level in opaque minerals such as granite, basalt, tuff, and heavily irradiated rock salt, a photoacoustic spectrometer (PAS) has been put into operation. Now under way is a series of measurements designed to evaluate this instrument and to develop the techniques needed to make meaningful radiation damage measurements. For example, it will be necessary to demonstrate that the PAS data can be reliably converted into optical absorption spectra. At the moment this is being evaluated by comparing spectra from samples measured in both the PAS machine and in a tramsnission spectrophotometer. This comparison will be possible for samples with optical density less than 3 or 4; other techniques will have to be used for higher density samples.

Also, a PAS measurement will expose samples to intense light which will optically bleach some or all of the color centers present. PAS measurements on irradiated rock salt show that each time a spectrum is measured the F-centers are reduced and colloid, M, and possibly R-centers are formed; little change is observed at other wavelengths except possibly near 200 nm. These bleaching effects are quite large. However, it is expected that they can be corrected by extrapolating from one or more measured spectra to the premeasurement condition.

It is encouraging to report that preliminary PAS measurements on Climax Stock granite show the expected radiation-induced changes.

Theoretical Dislocation Studies

Studies to determine which rock salt dislocations are likely sites for nucleating sodium metal colloid particles during irradiation have been completed, in the most useful elastic constant range, for the <001> edge dislocation and are now being made for the <111> edge dislocation. The <111> dislocation is formed by the interaction of mobile dislocations on intersecting slip planes. Completed during the past quarter was the solution of the continuity equation for the <111> edge dislocation. As in the <001> dislocation calculation, only the drift flow part of the diffusion is being considered. In this case, the flow of defects to the dislocation is controlled solely by the defect-dislocation interaction. The solution of the drift flow equation involves three sets of characteristics. One gives the flow lines along which the defects move to the dislocation. A second gives the boundaries of the depletion zone, the region about the dislocation which is depleted of defects at time t. The third gives the distribution of defects outside the depletion zone. These characteristics are all functions of the <111> anisotropy parameter h, which is analogous to the parameter H for the <001> edge dislocation. The permissible values of h lie in the interval $0 \leq h < 1$.

Although computer plots of flow lines, equipotentials, depletion zone boundaries, and defect concentration remain to be obtained, a number of important features of the solution can be ascertained where analytical results exist:

Flow Lines. In the interval $0 \le h < h_0 \simeq 0.316$, the flow lines are closed loops which bring defects to the dislocation. There are two symmetric sets of loops, one on either side of the dislocation. For $0.316 \simeq h_0 < h < 1$ some flow lines are closed loops. For $h_0 < h < 1/3$ there is one set of closed loops on each side of the dislocation. For $1/3 < h < 1$ there are three sets of closed loops on each side of the dislocation. In addition to the closed flow lines there are open flow lines for values of h in the interval $h_0 < h < 1$. For defects which expand the elastic medium, the open flow lines below the dislocation, i.e., below the $\{11\bar{2}\}$ plane, continuously bring defects to the <111> edge dislocation. Defects on the open flow lines above the $\{11\bar{2}\}$ plane are repelled to two common planes symmetric about the dislocation. Hence, analogous to the <001> edge dislocation result, the dislocation-defect interaction leads to two mechanisms for defect agglomeration.

Defect Concentration. An analytical solution has been obtained for the defect concentration outside the depletion zone of the <111> dislocation. The defect concentration is uniform only for isotropic, $h = 0$, material. For $h \neq 0$ the defect concentration is a function of angle about the dislocation. For $0 < h < 1$ it contains singularities normal to the $\{11\bar{2}\}$ plane. For $h_0 < h < 1$ there are additional singularities in the defect concentration expression.

FUTURE ACTIVITIES

Radiation damage studies on rock salt from different localities and different horizons at various sites will continue, with emphasis on U.S. salt dome samples. Any additional time available will be used to study dose rate effects in natural rock salt.

Measurements on gas evolution from rock salt before, during, and after irradiation should begin.

Theoretical studies to determine which dislocation-related properties are important for nucleating colloid particles should reach the final stage for the <111> dislocation.

The analysis of data on heat-induced colloid formation in salt irradiated at room temperature and on thermoluminescence data for natural and synthetic salt will continue.

The development of techniques for studying radiation damage in opaque and translucent minerals will continue, primarily using the photoacoustic spectrometer.

REFERENCE

Levy, P. W., K. J. Swyler, and R. W. Klaffky, 1980. "Radiation Induced Color Center and Colloid Formation in Synthetic NaCl and Natural Rock Salt", Journal de Physique, Vol. 41, p. 344.

WBS 1.4.2

PROJECT: Radiation Chemistry of Salt Mine Brines and Hydrates

PRINCIPAL INVESTIGATOR: Oak Ridge National Laboratory (G. H. Jenks)

ONWI PROJECT MANAGER: G. E. Raines

OBJECTIVE

The objective of this program is to experimentally establish the values for $G(H_2)$ and G (accompanying oxidants) in salt mine brines and hydrates ($MgCl_2$ hydrates) under gamma irradiation at temperatures up to about 450 K, for some solutions for which the vapor pressure does not exceed about 0.3 MPa at the test temperature. The G-value is a measure of product yield during radiolysis. It is defined as molecules of product over 100 eV of energy absorbed by the system. The radiolytic products from brine irradiation may have deleterious effects on package components via hydrogen embrittlement or enhanced corrosion.

PROGRESS REPORTED PREVIOUSLY

This project began 1 October, 1979. Experimental work was completed 30 September, 1980. A topical report covering this work has been in preparation.

ACTIVITIES DURING THE REPORTING PERIOD

The topical report of this work is in publication and has the report No. ORNL-5726 (Jenks and Walton, 1981). Information from the abstract of the report is presented in the following.

The work comprised an experimental study of certain aspects of the radiation chemistry of NaCl-saturated $MgCl_2$ solutions and $MgCl_2$ hydrates at temperatures in the range of 30 to 180 C. The principal objective was to establish values for the yields of H_2 and accompanying oxidants in the gamma ray radiolysis of concentrated brines that might occur in waste repositories in salt.

It was concluded that the yield of H_2 from gamma-irradiated brine solution into a simultaneously irradiated, deaerated atmosphere above the solution is between 0.48 and 0.49 over most of the range from 30 to 143 C. The yield is probably somewhat lower at the lower end of this range: $G(H_2) = 0.44$ average at 30 to 45 C. Changes in the relative amounts of $MgCl_2$ and NaCl in the NaCl-saturated solutions have negligible effects on the yield.

The yield of O_2 into the deaerated atmosphere in the systems described in the preceding paragraph is 0.13 average, independent of the temperature and brine composition. This shows that only $\sim$50 percent of the radiolytic oxidant which was formed along with the H_2 was present as O_2. The species which compose the remainder of the oxidant were not identified.

It was also concluded that the yield of H_2 from a gamma-irradiated brine solution into a simultaneously irradiated atmosphere containing 5 to 8 percent air in He may be greater than the yield in deaerated systems by amounts ranging from 0 percent for temperatures of 73 to 85 C to about 30 to 40 percent for temperatures in the ranges 100 to 143 C and 30 to 45 C, respectively. The mechanisms by which the air affected the yields of H_2 and O_2 were not established.

The values for $G(H_2)$ in deaerated systems found in this work are in approximate agreement with the value of 0.44 for the gamma irradiation yield of H_2 in pure H_2O at room temperature. They are also in agreement with the values predicted by extrapolation of the findings of previous workers for the value for $G(H_2)$ in 2 M NaCl solutions at room temperature. They are in poorer agreement with the value $[G(H)_2 = 0.42]$ for NaCl-saturated solutions in the range 0 to

85 C stated by Spitsyn, Kabakchy, and Barsova (1980). The higher values for $G(H_2)$ in brine (∿2) inferred by Jenks from results with KCl solutions reported by previous Russian workers are completely discounted.

The indication of effects of 5 to 8 percent air on the values for $G(H_2)$ apparently does not agree with the stated findings of Spitsyn, et al (1980)[i.e., that the value for $G(H_2)$ in salt solutions is independent of O_2].

Additionally, it was concluded that deaerated solutions containing 10 M to 12 M $MgCl_2$ and irradiated at 150 to 180 C exhibit values for $G(H_2)$ which are greater than those for solutions of lower $MgCl_2$ concentrations at lower temperatures by factors which range from ∿1.0 to 1.25 at 150 to 160 C to 1.6 to 2.0 at 170 to 180 C. Presumably, the increased hydrolysis of $MgCl_2$ at higher temperatures and concentrations is responsible for some or all of the increase in $G(H_2)$. Also it was found that radiolytic decomposition of the water of hydration in crystals of $MgCl_2 \cdot 6H_2O$ takes place, but the effective values for $G(H_2)$ are much less than those in a liquefied solution with the same ratio of $MgCl_2$ to H_2O. Most of the H_2 is not released from the crystals until the irradiated material is heated above the liquefaction temperature.

Some suggestions for additional experimental work are presented which would help in (1) identifying the several oxidized species which are apparently formed in the radiolysis of brine solutions, and (2) further clarifying the radiolysis in the brines.

Arrangements were made during this period to conduct additional experimental studies of the radiation chemistry of salt mine brines. The tentative objectives of these studies are to establish the effects of air on $G(H_2)$ and $G(O_2)$ and to identify the radiolytic oxidant species which may be formed in place of O_2. Analysis for Cl_2, H_2O_2, ClO_3^-, ClO_4^-, and CO_2 will be made.

REFERENCES

Jenks, G. H., and J. R. Walton, 1981. Radiation Chemistry of Salt Mine Brines and Hydrates, ORNL-5726, Oak Ridge National Laboratory, Oak Ridge, TN.

Spitsyn, V. I., S. A. Kabakchy, and L. I. Barsova, 1980. "Physico-Chemical Processes in Rock Salt Under Irradiation", in Scientific Basis for Nuclear Waste Management, Vol. 2, edited by Clyde J. M. Northrup, Jr., Plenum, New York, NY, pp. 561-567.

WBS 1.4.2

PROJECT: Long-Term Monitoring and Analysis of the Avery Island Heater Experiments

PRINCIPAL INVESTIGATOR: RE/SPEC, Inc. (L. L. Van Sambeek)

ONWI PROJECT MANAGER: W. F. Ubbes

OBJECTIVE

The objective of the investigations at Avery Island is to acquire thermal and mechanical salt response data that will aid in the identification and understanding of the various responses of domal salt to imposed heating conditions. The transfer of heat into the salt formation results in increased temperatures which induce thermomechanical and possibly thermochemical responses. The data obtained during these investigations will be used to either develop models describing the various responses or test existing models and assess their capabilities for describing the responses.

PROGRESS REPORTED PREVIOUSLY

Three heater tests in the Avery Island salt mine were in operation by 1 June, 1978. The design of the brine movement experiments began in February, 1979; the experiments were in operation by 1 October 1979. The brine movement experiments are now in a post-test evaluation stage. Specifications and designs for the additional studies have been developed, and the experiments are in operation.

ACTIVITIES DURING THE REPORTING PERIOD

Heater Tests

The post-test evaluation of the Sites A and B heater tests was continued during the quarter. Activities included the removal of the Site B heater and sleeve assemblies and continued data-gathering activities at both sites.

Special attention was given to measuring the heat flux from the floor during the cooldown at Site A. The results from these measurements indicate that the convective film coefficient during cooldown was 1.8 Btu/hr-ft^2-F. When the heater test was started some 2 years ago, coefficient values between 1.2 and 1.6 were measured. The difference is attributed to a change in the heat flux meter geometry and daily cleaning of the dust from the meter surfaces. During the early period of the test, a PVC pipe was placed around the meter for protection. The pipe had a length of about 2 inches, which partially shielded the meter from the ventilation. This pipe was removed during the operation of the heater test; however, the floor had already experienced most of its temperature rise. Since the calculation of the film coefficient requires several data points dependent on the temperature rise of the floor, the heat flux coefficient could not be fully determined during the operation of the test. The film coefficient of 1.8 Btu/hr-ft^2-F is probably close to the true value for the Avery Island situation.

Examination of the Site A temperature data indicates that a convection cell developed between the heater sleeve and the borehole wall. The development of a convection cell during cooldown is reasonable, even though one apparently did not exist during the heating phase. The annulus between the sleeve and the heater borehole at an elevation near the top of the heater became blocked with a recrystallized salt bridge within the first 10 days of the test. This bridge eventually expanded upward to at least a 5-foot elevation. As long as the annulus was totally closed, no steam could rise above the heater location. During the cooldown, however, both the diameter of the sleeve and the salt would shrink slightly due to cooling. This might have allowed for an opening between the sleeve and the recrystallized salt. Once steam penetrated this opening, traveled to the cooler region, condensed, and trickled downward while dissolving the recrystallized salt, the opening could have been rapidly enlarged. This process would thus provide heat transfer in the vertical direction.

Brine Movement Studies

During April the Site NB (natural brine) brine movement experiment was terminated. The power of the NB central heater was reduced over 30 days instead of the 5-day power reduction period used at Site SB (synthetic brine). At Site SB the rate of moisture collection and the measured permeability both increased significantly as the power was reduced. It appears from these data that thermal cracking of the salt surrounding the heater borehole at Site SB occurred during the 5-day power reduction. Therefore, a 30-day power reduction period was selected for Site NB to avoid rapid cooldown of the salt which could result in thermal fracturing. Permeability measurements were not made during the Site NB power reduction, but moisture collection from the heater borehole was continued throughout the power reduction period. No significant increase or decrease in the Site NB moisture collection rate was noted during the 30-day power reduction period.

During June the Site SB overcore was completed at a final depth of 19 feet 7 inches. A total of 11 sections of 16-inch-diameter core were recovered from the borehole.

Additional Studies

Two of the Phase II accelerated borehole closure experiments were activated during June. Both were ambient temperature tests, one at 10.6 MPa (1,540 psi) and one at 14.84 MPa (2,150 psi). Measurements of borehole diameter for both tests were made at frequent intervals for the first 12 hours of operation. After the first day of operation, the diameter measurements were made twice a day for a period of about ten days, after which one measurement per day was made for each test. Creep closures, time-dependent change in borehole diameter, for the two tests are shown in Figures 1 and and 2. Also shown in the figures are the predicted borehole closures due to creep as determined from finite-element analysis.

FUTURE ACTIVITIES

During the next quarter, the Phase II accelerated borehole closure tests will be continued. Also, the post-test evaluation of the Sites A and B heater tests will continue with overcoring activities at Site B and hardware removal at Site A. A draft report covering the heating phase of Site A and Site B will be completed.

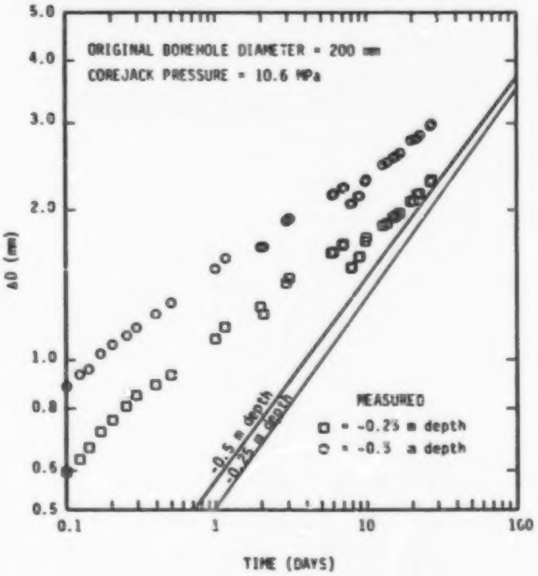


Figure 1. Comparison of the Measured and Predicted Creep Closure, ΔD, in Test AT-10.

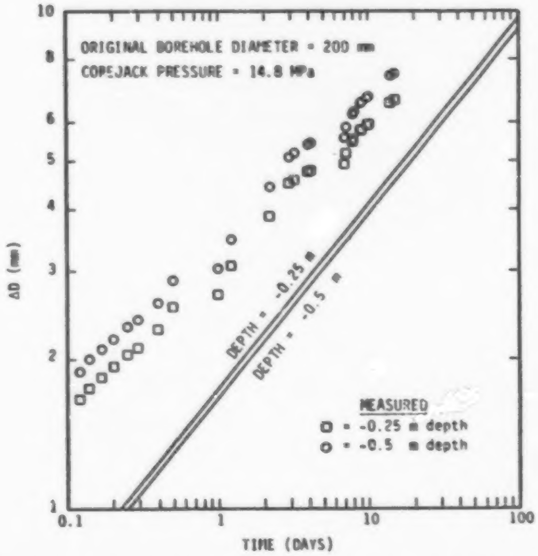


Figure 2. Comparison of the Measured and Predicted Creep Closure, ΔD, in Test AT-15 (core jack pressure = 14.8 MPa).

WBS 1.4.2

PROJECT: Rock Behavior Under Elevated Pressure and Temperature

PRINCIPAL INVESTIGATOR: Lawrence Livermore National Laboratory (H. C. Heard)

ONWI PROJECT MANAGER: M. M. Lemcoe

INTRODUCTION

The overall objective of the program is to develop an understanding of rock behavior under elevated pressure and temperature such that the response in space and time of a mined heated cavity in these rocks can be predicted. In order to do this, measurements are made in the laboratory at simulated, deep in situ conditions. It is expected that these data will be correlated with field observations and later incorporated into a model for prediction.

TASK 1: THERMAL PROPERTIES OF ROCKS

OBJECTIVE

The objective is to determine the thermal conductivity, thermal diffusivity, and thermal expansion of candidate waste repository rocks at in situ conditions of temperature, pressure, and fluid content.

PROGRESS REPORTED PREVIOUSLY

This task started in August 1977. Making measurements under the attempted conditions of temperature (to 300 C) and pressure (to 50 MPa) in the presence of pore fluid required an advance in measurement state of the art for rocks; an apparatus was designed. In the course of debugging it, a run was made on an unjacketed aluminum sample that showed the basic design to be viable.

Since that time, the thermal conductivity and thermal diffusivity behavior of duplicate samples of Avery Island salt and Climax Stock quartz monzonite (CSQM) have been determined to 300 C and 50 MPa pressure.

ACTIVITIES DURING THE REPORTING PERIOD

Calibration of the thermal conductivity measurement has been achieved with the completion of the run on the reference standard of GE 124 fused silica. Data were taken to 50 MPa and 200 C, as planned.

The qualitative indications of the reference standard data for CSQM are reported in a draft report about the thermal properties of CSQM. The correction to thermal conductivity in that report is based on an estimated conductivity for the standard of 1.11 W/mK at room temperature. The actual conductivity will be forthcoming, and the report will be amended for the correct conductivity and appended with the conductivity at elevated temperature.

Preparation for microscopy of the 14 heat-treated CSQM samples is complete. Six of the samples spanning a wide range of pressures and temperatures have been studied and photographed by scanning electron microscopy. Qualitatively these samples show the expected increase of microfracturing with higher temperature and lower pressure, but the effect is more subdued, that is, difficult to pick out, than had been expected. The goal of the microscopy will be quantitative confirmation of the porosity change data predicted from thermal expansion measurements at pressure and temperature.

FUTURE ACTIVITIES

Planned activities next quarter include the completion of the basalt test sample, completion of jacketing procedures, and completion of conductivity and diffusivity measurements on this rock. In addition, the SEM measurements on the CSQM samples will be furnished, and all of the fused quartz calibration data will be analyzed.

TASK 2: WATER TRANSPORT: PERMEABILITY AND RELATED MEASUREMENTS

OBJECTIVE

The objective is to make systematic measurements of the permeability of intact and fractured rock as a function of confining pressure, pore pressure, and deviatoric stress. In order to extend the usefulness of the data, simultaneous measurements of fracture displacement, strain, electrical conductivity, and acoustic velocity and amplitude are also carried out.

PROGRESS REPORTED PREVIOUSLY

This task started in June 1976. A summary of progress includes four major items.

Two complete sets of apparatus were designed and installed to determine the permeabilities of large rock samples (15 cm diameter by 28 cm long) in the range of 10^{-11} to 10^{-24} m^2. Pressures may range to in excess of 50 MPa; temperatures remain constant at 20 C. These data are taken simultaneously with the principal imposed stresses and strains, acoustic velocities and pulse amplitudes, electrical conductivities, and displacement of a fracture (if present). A microprocessor system controls the test and records the data.

Measurements of the above type were completed on intact samples of Westerly granite, White Lake gneissic granite, and Creighton gabbro, and on fractured samples of Westerly granite, Stripa granite, CSQM, and Creighton gabbro. Testing is under way on intact samples of CSQM and Stripa granite.

Failure envelope data were completed on unfractured Westerly granite, Stripa granite, White Lake gneissic granite, Montello granite, Climax quartz monzonite, and Creighton gabbro.

Additional permeability testing on intact samples (6 cm diameter by 10 cm long) of Climax and Stripa rock was begun in a third automated apparatus at pressures ranging to 50 MPa.

ACTIVITIES DURING THE REPORTING PERIOD

Permeability tests now under way in Units I and II on intact samples of CSQM and Stripa granite are nearly completed. Preliminary analyses of the test data indicate very high-quality results. Similar tests on the same rocks, but on smaller samples (6 cm diameter by 10 cm long), also continue in the multiple sample apparatus.

High-quality surface profiles can now be measured along the surfaces of the laboratory fractured test samples. A data analysis routine to process these data is now about one-third completed.

FUTURE ACTIVITIES

When the current tests now under way in Units I and II are completed, work on an intact Umtanum basalt sample and a fractured Montello granite sample will begin.

Several more smaller samples (6 cm diameter by 10 cm long) of the Climax and Stripa rocks will be measured. Work on intact Montello granite and Umtanum basalt will take place at 20 C, and elevated temperature testing will begin later.

TASK 3: PRESSURE AND TEMPERATURE DEPENDENCE OF ROCK ELASTIC CONSTANTS

OBJECTIVE

The objective is to determine the elastic moduli of a suite of candidate repository rocks as a function of temperature and pressure. These measurements, including Young's modulus, bulk modulus, and thermal expansion, are necessary to understand and predict repository behavior after emplacement of the waste.

PROGRESS REPORTED PREVIOUSLY

This task started in June 1979. A summary of progress through March 1981 includes the following major items:

1. Determination of the thermal expansion characteristics of CSQM to pressures of 27.6 MPa at 300 C. Results of this study on expansion and its relationship to in situ permeability have been published.
2. The pressure and temperature dependence of Young's modulus, bulk modulus, and coefficient of thermal linear expansion had been determined for CSQM and Creighton gabbro up to 55 MPa at 350 C. These data are based on nine samples: three each from the three principal directions in the parent rock. Results have been published.
3. Results similar to No. 2 above were determined and analyzed for the Stripa and Westerly granites.

ACTIVITIES DURING THE REPORTING PERIOD

Nine test samples from each of the Umtanum and Pomona flows from Washington have been prepared for testing. As for the previous studies, three samples from each of the three orthogonal directions were fabricated. Testing has begun.

FUTURE ACTIVITIES

The report summarizing the elastic moduli, thermal expansion, and permeability results for the Stripa and Westerly granites will be revised. One basalt will be measured and all data analyzed. Measurements on a second basalt will begin.

WBS 1.4.2

PROJECT: Materials Properties and Stress Measurement Techniques

PRINCIPAL INVESTIGATOR: Lawrence Berkeley Laboratory

ONWI PROJECT MANAGER: M. M. Lemcoe

TASK 1: MATERIALS PROPERTIES TESTING PROGRAM SMALL-CORE TEST FACILITY

(N. Cook and L. Myer)

OBJECTIVE

In situ experiments in the Stripa Mine, Sweden, have yielded a great volume of data on the thermomechanical response of a granite rock mass to the heat that might be produced by buried nuclear waste. For proper analysis of the data from these experiments, it is necessary to have additional data in the form of thermomechanical properties obtained from rock samples tested in the laboratory. It is the objective of the materials properties test program to study and acquire thermomechanical properties (e.g., Young's modulus, Poisson's ratio, and thermal coefficient of expansion) using drill core from the Stripa Mine experimental areas.

PROGRESS REPORTED PREVIOUSLY

The materials testing program began in FY 79. Early in the program, work began on a stiff triaxial test machine capable of providing a confining pressure of 70 MPa, test temperatures up to 200 C, and a maximum axial load of 1.4 meganewton. The test cell will accommodate either 56 or 62-mm-diameter core of a length-to-diameter ratio of 3 to 1. Installation of the test apparatus in the laboratory was completed in mid-FY 80. Several improvements have been made on the equipment, the most recent of which was the addition of a computer-driven electro-servo control system. This system, allowing considerable generality in compressive loading or displacement paths, was completed in mid-FY 81.

Testing of intact samples of 62-mm-diameter core has been in progress, with several interruptions for technical improvements, since late FY 80. Preliminary results have demonstrated a pressure and temperature dependence of the thermomechanical properties for intact Stripa granite. Thermal expansion increases with increasing temperature and decreases somewhat with increasing pressure. Effects of pressure and temperature on the elastic moduli have been less pronounced, although at pressures less than 30 MPa increasing temperatures lead to decreasing values of Young's modulus.

ACTIVITIES DURING THE REPORTING PERIOD

Development and checkout of the software for computer control of the electro-servo system was completed. The software permits test control via simple commands entered at a video terminal. For example, one command signals the system to collect data. Another initiates a stress-strain test which is then performed at a designated rate up to a specified load. Testing proceeded under operator supervision for 16 hours per day, five days a week. Unattended during off-hours, the computer maintained constant pressure conditions in the test cell.

Two tests were completed by the end of May. With a downtime of about 10 days between samples, this is a representative throughput for the extensive testing being performed.

A calibration test was performed using an aluminum sample of known properties. Two transducers, the table LVDT and confining pressure pump direct current differential transducer (DCDT), are external to the test cell. Thus, measurements made by these transducers contain a component representing the deformations of various elements of the test system. A system calibration was therefore necessary for meaningful interpretation of the data from these external transducers. The aluminum cylinder was subjected to the same testing sequence as the rock samples. Through knowledge of the properties of the aluminum and by using the data from strain gages mounted on the sample, the contribution of the machine to deformations measured by the transducers was determined.

Rock sample deformations are primarily monitored by strain gages, as well as the table LVDT and confining pressure pump DCDT. Having redundant systems, however, provides greater confidence in the data. In addition, a persistent problem of drifting strain gages on rock samples at temperatures in excess of 190 C has necessitated reliance upon LVDT data for determination of sample thermal expansion at the highest test temperature.

Analysis of data continued through the reporting period. Reduction of the large volume of data generated during a test has been done using computer programs; the software has been expanded to include graphics.

Additional tests provided further verification of general trends reported previously. Scatter in results to date is limited for Young's modulus (E), but is considerable for thermal expansion measurements. In Figures 1 and 2, thermomechanical properties are compared for two samples from the same corehole, E2. One sample was taken from the top of the hole; the other came from a depth of about 4.4 meters in the hole. Tangent values of E at 55 MPa and 2 MPa confining pressure are compared in Figure 1. At 55 MPa, E was constant, but at 2 MPa, E was determined as the tangent (at a deviator stress of 60 MPa) of the best fit curve through the stress-strain data. The figure shows the effects of confining pressure and temperature on E as well as the limited scatter between samples.

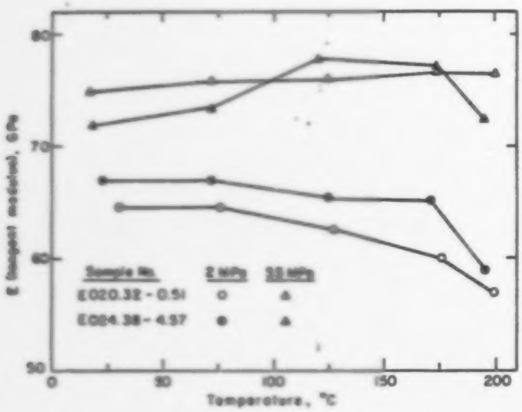


Figure 1. Comparison of Tangent Values of Young's Modulus for Two Samples at 2 MPa and 55 MPa Confining Pressures. (Data points are from polynomial regression analysis of stress-strain data.)

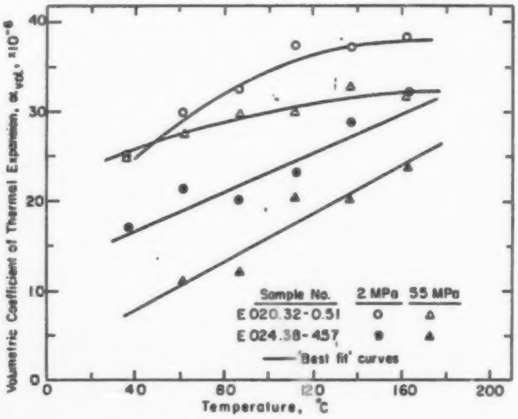


Figure 2. Comparison of α_{vol} for Two Samples at 2 MPa and 55 MPa Confining Pressures. (Solid lines represent result of polynomial regression analysis.)

Figure 2 presents values of the volumetric coefficient of thermal expansion (α_v) for the same samples at 55 MPa and 2 MPa confining pressure. Again, for each sample, the effects of confining pressure and temperature on α_v can be seen, but the scatter between samples is large, exceeding differences due to changes in confining pressure or temperature. Reasons for the scatter are speculative at present, although it may represent the natural variability in the rock mass. Additionally, it is interesting to note that the larger values of α_v were obtained from the sample near the top of the corehole. This hole was drilled from an underground room so the properties of the sample may have been influenced by blasting for excavation of the room.

Discrete data points in Figure 2 represent values of α_v determined by assuming a straight-line relationship between adjacent data points, whereas the smooth curves represent values of α_v derived from a polynomial regression analysis of the thermal expansion data. The shape of the curve is related to the degree of polynomial selected as the best fit of the data and does not have any particular physical significance. Curve fitting, although useful in smoothing and sometimes in defining trends, should not be considered a replacement for sound theoretical work in defining functional relationships between variables. Use of regression analysis of the thermal expansion data, in fact, reflects the need for further theoretical work in the area of thermomechanical constitutive relations for rock, to better define the functional relationship between thermal expansion and temperature.

FUTURE ACTIVITIES

Because of the observed scatter, the Stripa thermomechanical analysis test schedule will be altered to emphasize the study of variability of properties in the rock mass. Thus, tests at 30 MPa and 2 MPa confining pressure will give way to provide time for testing one or two additional samples this fiscal year. Intact samples will continue to be tested, although testing of at least one intact fractured sample is also planned.

TASK 2: STRIPA IN SITU STRESS MEASUREMENTS

(T. Doe)

OBJECTIVE

The objectives of this program are twofold: (1) to provide in situ stress data for interpreting the heater and hydrology experiments at Stripa and (2) to compare and assess two different methods of in situ stress measurement. During 1980 the goal was to perform both hydraulic fracturing and overcoring stress measurements in SBH-4, a vertical hole drilled from the surface north of the Stripa Mine. Both types of measurements were performed from depths 100 meters or less to 300 meters.

The data obtained from the SBH-4 work will provide far-field stress values for the thermomechanical modeling of the Stripa heater experiments. The objectives of the 1981 field work are to complement the SBH-4 far-field stress measurements with near-field measurements close to the underground test areas. Hydraulic fracturing will be used in addition to USBM gage, Leeman triaxial cell, and CSIRO gage methods as a means of combining the results of different measurement methods. These near-field underground stress measurements will play a key role in validating the mechanical numerical model of the Stripa tests.

PROGRESS REPORTED PREVIOUSLY

During the summer of 1980, a series of tests comparing the Swedish deep-hole Leeman triaxial cell and hydrofracturing stress measurement techniques in SBH-4 was completed. Preliminary analyses were made at the end of FY 80, prior to availability of modulus data for interpreting the overcoring stress measurements and tensile strengths for interpreting the hydrofractures. Laboratory test data for these properties were obtained during the first quarter of 1981.

Activities during the second quarter consisted of completing the data analysis of the stress measurements conducted in SBH-4 during the summer of 1980 and preparing the stress measurements to be performed underground at Stripa during the summer of 1981.

ACTIVITIES DURING THE REPORTING PERIOD

Final plans were made for the stress measurements, and a test plan was submitted to ONWI. The test plan called for the drilling of three holes in the area between the full-scale drift and the extensometer drift in the LBL test area at the Stripa Mine.

Test Plan

The first hole, designated BSP-1, is to be drilled for a length of 25 meters vertically from the center of the floor of the full-scale drift. A series of six measurements are to be made by the Swedish State Power Board using the deep-hole Leeman cell technique used in the 381-meter-deep hole tested last summer at Stripa. In addition to providing stress data for the area of the full-scale heater tests, the new series of measurements will provide a check of the Power Board results against other overcoring measurements in nearby holes. After overcoring, hydraulic fracturing measurements will be performed in the same hole.

The second hole, BSP-2, is to be used for overcoring by USBM borehole gage, Leeman triaxial cell, and CSIRO hollow inclusion cell. This hole is to be drilled 10 to 15 meters from the extensometer drift under the full-scale drift at an angle a few degrees up from the horizontal to allow for drainage. (The standard Leeman cell and the CSIRO cell require a dry borehole.)

Nearly parallel to BSP-2 but oriented slightly downward from the horizontal will be BSP-3, a hole for hydraulic fracturing measurements. In this hole, as in BSP-1, acoustic measurements will be made to determine the location of the propagating hydrofracture. This aspect of the Stripa stress measurement program is considered especially important in light of the controversy surrounding assumptions on hydrofracture orientation.

Status of Measurements

The overcoring measurements and the drilling were completed. The hydraulic fracturing equipment arrived in Sweden and has been bench-tested. Results of the overcoring are not yet available.

FUTURE ACTIVITIES

The hydraulic fracturing measurements will be made, along with the acoustic monitoring. A draft report, including the results of all the measurements, will be submitted by the end of the fiscal year.

TASK 3: POST HEATER DRILL-BACK INVESTIGATION

(H. Wollenberg)

OBJECTIVE

The objective of this task is to investigate the effects of the now complete heating/cooling cycle on the Stripa H-10 heater borehole and adjacent granite rock mass. This is to be accomplished by the drilling and TV logging of two new boreholes intersecting the heater location. Core samples will be shipped to Berkeley for laboratory examinations.

During FY 81, the project will be completed by continuing the petrographic study of the post-test cores to detect changes in fracture parameters, microfracture intensity, fracture-filling material, and rock-forming minerals. Mechanical properties such as Young's modulus, Poisson's ratio, and the coefficient of thermal expansion for fractured and intact core samples will be measured for comparison with pretest samples. The heater hole photographic data will be analyzed to relate the three-dimensional spalling pattern to the theoretical thermal stress.

ACTIVITIES DURING THE REPORTING PERIOD

After a six-month dormancy, this project was reactivated on 1 April, 1981, with three subtasks: (1) petrology of cores into and through the rock heated by the H-10 heater, (2) topography of the decrepitated H-10 hole walls, and (3) determination of mechanical properties of the heated and unheated rock.

For the petrologic studies, a set of thin sections of heated, moderately heated, and unheated core from hole DBEX-1 was prepared. Petrographic examinations indicate that the chlorite, which fills microfractures and rims some mineral grains, is reddish-brown in the strongly heated rock within a few centimeters of the wall of the H-10 hole, compared to its more usual greenish color in the less heated quartz monzonite. Initial X-ray diffraction measurements have been made on the chloritic material and on mica of the heated and unheated rock to determine if any changes in crystallographic parameters took place due to heating. Sections of representative rock have been made for electron microprobe transects to discern if major and trace elements might have migrated in the rock in response to heating. The intensity of microfracturing is being recorded to determine the effects of heating on the rock fabric.

Attempts to produce contour maps of the spalled zone on the H-10 borehole wall from stereoscopic photographs have been unsuccessful so far because of the position of the camera with respect to the borehole wall.

FUTURE ACTIVITIES

Petrologic studies will continue next quarter and will be reported. Mechanical properties measurements may be made in FY 82 as part of a related material properties testing program.

WBS 1.4.2

PROJECT: Swedish Cooperative Project

PRINCIPAL INVESTIGATOR: Lawrence Berkeley Laboratory (N. Cook)

ONWI PROJECT MANAGER: W. F. Ubbes

OBJECTIVE

Since the field activities for the Swedish American Cooperative Project were concluded at the end of FY 80, the FY 81 effort focuses on the final documentation of field results obtained from the previous year's activities.

The final documentation will include results obtained from the macropermeability, thermomechanical, and geophysical investigations and will be published as SAC reports in a form which will allow LBL, ONWI, or ONWI subcontractors to use these data for independent analytical purposes.

PROGRESS REPORTED PREVIOUSLY

Work accomplished in the third quarter included compilation of (1) the data base resulting from fracture mapping and core logging in the full-scale heater experiment drift, (2) the records of ground water infiltrating into heater and instrumentation boreholes during the operation of the three heater experiments, (3) the thermocouple calibration data, and (4) the extensometer performance. Draft reports were written on the data base and extensometer performance compilations.

ACTIVITIES DURING THE REPORTING PERIOD

The SAC report, Water Inflow Into Boreholes During the Stripa Heater Experiments, was completed. The report is based on volumes of water retrieved from instrumentation and heater holes by the dewatering apparatus. Inflow into many of the holes increased dramatically following turn-on of the various heaters. This flow declined in the subsequent months, sometimes to zero inflow. In holes which continued to flow while the heaters operated, sharp decreases in inflow occurred when heater power was decreased or stopped. Amounts were generally quite small, compatible with volumes that could be removed from rock by very small changes in rock pore space. Heat loss due to water extraction was less than 3 percent for the highest flow hole, and less than 1 percent for most heater holes. The water inflow data also furnished an instance of fracture flow connectively over a distance of some 40 meters. When a borehole 40 meters from the time-scale drift was packed off and isolated, inflow into the time-scale heater holes increased dramatically, demonstrating the existence of permeable flow paths among a number of boreholes. Overall, the water inflow data furnish constraints which must be taken into account in the interpretation of the Stripa heater experimental data.

Work neared completion on the thermocouple and temperature measurement evaluation during this quarter. As reported previously, temperature errors in the computer-acquired data base which were caused by malfunctions in the computer's data acquisition system have been diagnosed and compensated. These compensations appear adequate for all but a few specialized purposes. The thermocouples themselves were calibrated at the site before the experiments and twice afterward. Two of these calibrations were biased by self-heating of the resistance temperature detector reference, and one calibration was biased by improper zeroing of a precision ohmmeter. These effects have been removed, and the calibrations have been compared with the applicable NBS voltage-temperature relationship. Plots of families of thermocouples, with the voltage error presented as a function of the temperature of the calibration oven, illustrate the variability of individual thermocouples and variability among classes of thermocouples. The deviation plots have been fitted with curves giving the mean and standard deviation departure from the NBS values. Overall errors in the computed data base for the Stripa heater experiments are a combination of these deviations, plus very small residual errors from the data acquisition system.

The report concludes with eight recommendations on the use of thermocouples in future experiments in an underground environment.

Two SAC reports were published and distributed during the reporting period: Thermal and Thermomechanical Data From In Situ Heater Experiments at Stripa (LBL-11477, SAC-29) and The Effect of Radon Transport in Groundwater Upon Gamma Ray Borehole Logs (LBL-11180, SAC-30).

SAC reports in press during the reporting period include: Strength and Permeability Tests on Ultra-Large Stripa Granite Core (LBL-11203, SAC-31) and Ultrasonic and Acoustic Emission Results From the Stripa Heater Experiments (LBL-10975, SAC-32).

FUTURE ACTIVITIES

Final publication of The Effect of Radon Transport in Groundwater Upon Gamma Ray Borehole Logs, Strength and Permeability Tests on Ultra-Large Stripa Granite Core, and Ultrasonic and Acoustic Emission Results From the Stripa Heater Experiments is anticipated for the next quarter.

WBS 1.4.2

PROJECT: Stripa Testing Project

PRINCIPAL INVESTIGATOR: Swedish Nuclear Fuel Supply Co., Safety Board Division (SKBF/KBS) (L. Nilsson, Coordinator)

ONWI PROJECT MANAGER: R. A. Robinson

TASK 1: HYDROGEOLOGIC INVESTIGATIONS IN BOREHOLES

(L. Carlsson and T. Olsson, Geological Survey of Sweden)

OBJECTIVE

The objectives of the hydrogeologic investigations in boreholes are as follows:

1. Methodology development for hydrogeologic and hydrogeochemical investigations in subsurface nearly horizontal and vertical boreholes.
2. Instrumentation and equipment development in subsurface nearly horizontal and vertical boreholes.
3. Hydraulic, chemical, and isotopic characterization of the Stripa granite and ground waters.

PROGRESS REPORTED PREVIOUSLY

It was decided to carry out the investigations in three core-drilled boreholes, one 1,000-meter-deep vertical hole (V1) and two 300-meter-long nearly horizontal holes (N1 and E1). These will be drilled from a specially prepared site situated at the 360-meter level in the mine. In the vertical hole, priority has been given to hydrogeochemical studies, and a minor program for hydraulic testing will follow the hydrogeochemistry.

The main purpose of borehole N1 will be to develop testing methods in horizontal boreholes regarding hydraulic and chemical properties. TV inspection and geophysical logging will also be included.

The nearly horizontal borehole E1 is justified in terms of the requirements for developing methods to measure the permeability tensor from horizontal boreholes.

ACTIVITIES DURING THE REPORTING PERIOD

During the period no drilling in V1 took place because the poor rock quality in the lower part of V1 (between 450 and 506 meters) makes it necessary to stabilize the borehole before continuing the drilling. The stabilization will, however, damage the zone and reduce the value of hydraulic and hydrogeochemical investigations afterwards. It was therefore decided to wait as long as possible with the stabilization and focus the drilling operation on the two horizontal boreholes, both of which have been completed.

A grouting substance was sought that would affect the water chemistry as little as possible. It was decided to use a two-component silica polymer for the stabilization. This material, of French origin, is available under the name Hardener 1,000. Work is simultaneously in progress to find a reliable method for injecting it.

During this long, unexpected break in the drilling of V1, hydraulic testing and hydrogeochemical sampling were done to acquire as much knowledge as possible about the zone before grouting it.

The hydraulic testing was done with pressure buildup tests in which the hydraulic pressure was measured below a packer located 410 meters down in the borehole. The results of these tests show that the conductivity of the crushed zone is about $5 \cdot 10^{-8}$ m/s in accordance with the preliminary evaluation reported previously.

An interference test was begun between borehole V1 and DBH V1, the vertical borehole at the

410-meter level. In this borehole a packer was placed 356 meters deep to give the same Z-coordinate as the packer in V1. Results from this test so far give only a preliminary value for the conductivity in DBH V1, which is $3 \cdot 10^{-10}$ m/s.

The pressure buildup in both these boreholes is extremely slow, with a pressure of about 0.8 MPa in borehole V1 three months after shut-in and 0.1 MPa in DBH V1 after one month. Borehole N1 was also packed-off after its completion, and its pressure was as much as 3.1 MPa after one month. Borehole N1 has been geophysically logged.

The design of the packer system to be used in borehole V1 during the monitoring stage of the hydrogeochemical investigations has been completed. An extensive sampling for the hydrogeochemical work was done not only in the boreholes included in this study but also in other boreholes in the mine, such as DBH V1 and holes in the buffer mass test area.

Many samples of various elements and compounds were taken to be analyzed:

- Major cations/trace elements
- Major anions
- Aluminum
- Fe(III)
- Sulfide
- Dissolved oxygen content
- Nutrients.

Table 1 shows a compilation of the chemical composition of water from borehole V1 analyzed so far. Samples have also been taken for uranium, radium, radon, and inert gases.

Table 1. Water Analyses From 92 to 94 m Deep in Borehole V1.

Element or Compound	810114	810116
pH	7.6	8.4
Conductivity mmho/m	61.6	84.2
HCO_3 mg/l	65	17
F mg/l	2.2	3.2
Cl mg/l	174	245
PO_4 mg/l	<0.3	<0.3
NO_2 mg/l	0.037	0.037
NO_3 mg/l	2.3	2.6
SO_4	9.6	1.1
NH_4	0.20	0.10
Na mg/l	74	113
Mg mg/l	4.8	0.25
K mg/l	3.0	1.1
Ca mg/l	36	32
Mn mg/l	<0.01	<0.01
Fe mg/l	<0.01	<0.01
Be mg/l	<0.003	<0.003
Cr mg/l	<0.005	<0.005
Co mg/l	<0.005	<0.005
Ni mg/l	<0.005	<0.005
Cu mg/l	0.029	0.033
Zn mg/l	0.078	0.020
As mg/l	<0.003	<0.003
Sr mg/l	0.147	0.192
Pb mg/l	<0.010	<0.010

FUTURE ACTIVITIES

During the next quarter the following activities are planned:

- Stabilize the zone of poor rock quality in borehole V1.
- Continue drilling in V1 to reenter good rock.
- Continue water sampling in V1 on two occasions before stabilization in order to obtain a complete set of analyses from the water-yielding zone.

- Perform flow tests in V1 with interference analyses in DBH V1.
- Monitor the hydraulic head in boreholes N1 and E1.
- Construct a packer system for monitoring the hydrogeochemical program.

TASK 2: MIGRATION IN SINGLE FISSURE

(I. Neretnieks, Royal Institute of Technology, Sweden)

OBJECTIVE

This investigation has the following main objectives:

- To observe the movement of nonsorbing tracers under controlled and well-defined in situ conditions
- To interpret the movement of tracers in such a way that the results can be used to predict radionuclide migration
- To obtain a basis for comparing laboratory sorption data with in situ observations
- To develop good techniques for small-volume sampling of water and for investigating surfaces with sorbed tracers
- To gather experience with stable tracers before using radioactive tracers.

ACTIVITIES DURING THE REPORTING PERIOD

Plastic pellets, high-molecular-weight Dextran, sodium-fluorescein, and I^- were simultaneously injected, using an overpressure of 0.22 MPa.

Two suitable fractures for the main migration investigation have been located, and preparations for monitoring the water flow from the fractures have been carried out. The water flow from these fractures indicates that one of the fractures could be used in the main investigation.

FUTURE ACTIVITIES

During the next quarter, preparation of the test site to be used in the main investigation will start. Collection of water from the sampling holes in the preparatory experiment will continue. Analyses will be made, and the results will be evaluated.

TASK 3: BUFFER MASS TEST

(R. Pusch, University of Luleå, Sweden)

OBJECTIVE

The general objective of the buffer mass test (BMT) is to verify the suitability and function of the suggested buffer materials under real conditions on site. In addition, the interaction between the buffer materials and the confining rock will be investigated with respect to hydrology and rock mechanics.

ACTIVITIES DURING THE REPORTING PERIOD

Civil works, production of bentonite blocks, and testing and installation of the electronic recording and regulating systems dominated the reporting period. Also, extended work on the theoretical modeling of the water uptake and temperature development in the buffer materials took place.

Highly Compacted Bentonite

Blocks of highly compacted bentonite were manufactured during the period. Variations in water content of the MX-80 bentonite powder caused a reconsideration of the required initial bulk density, block dimensions, etc. Slight changes were made so that three of the heaters will be surrounded by bentonite with a water content of approximately 10 percent, while the other three will have bentonite blocks with about 13 percent water content. For the sake of comparison, the bulk density after complete water uptake should be equal for the two sets, so different volumes must be accepted. This problem was solved by choosing different slot widths (1 and 3 cm, respectively) and by applying bentonite powder in the wider slots. Through this arrangement, experience is gained in choosing among various bentonite densities, slot widths, and slot-filling techniques.

The blocks prepared for the first heater were transported down to the field laboratory so that the holes for gages and cables can be drilled.

Electronic Systems

The recording units have been tested often and found to operate according to the specifications. The regulating systems for the heater power need to be calibrated. All data loggers and computer equipment, as well as the remaining gages and cables, were transported to Stripa. The mounting racks were completed, and one of them was put in position, temporarily, for the connection of cables from the instrumented first heater.

Other Activities

A slight reprogramming has been necessary for the field test. Heater No. 1 will be in operation during the summer and will rest on the tunnel floor, wrapped in plastic to prevent evaporation. The choice of electrical power (100 W) is based on a calculation of a heater surface temperature of not more than about 40 C, which will cause only insignificant changes in the water content.

FUTURE ACTIVITIES

Work during the next quarter will include the following:

- Complete the first heater-bentonite arrangement, including connection of cables to the loggers via mounting rack No. 1; check the electronic system and start of heater No. 1 for a two-month test period at reduced power.
- Install electrically heated fans to keep the air temperature at about 25 C and to dewater the air to yield a relative humidity of less than 60 percent; record the amount of water collected from the fans (this should give a rough measure of the water inflow from the rock into the tunnel per time unit, similar to the LBL inflow measurement in the macropermeability test).
- Extend the large concrete slab with boxing-outs; apply the remaining electrical mounting racks.
- Build up the second heater-bentonite arrangement for a short test period.
- Lower the two heaters into the large holes in the rock.
- Apply the backfill and closing of the inner part of the tunnel; continue the test.

WBS 1.4.2

PROJECT: Experiment Development to Support Field Testing

PRINCIPAL INVESTIGATORS: Westinghouse Advanced Energy Systems Division (P. P. Zemanick, G. R. Kilp, and F. F. Klein) and D'Appolonia (L. Jarolimek)

ONWI PROJECT MANAGER: M. W. Anthony

OBJECTIVE

The principal objective is to develop test plans and hardware for future field tests to study (1) the phenomenon of brine migration in salt under simulated nuclear waste repository conditions, (2) waste-rock interactions under conditions simulating long-term barrier and waste degradation, and (3) the performance of engineered barriers under geological conditions.

PROGRESS REPORTED PREVIOUSLY

Work on this project began in December, 1979.

Brine Migration

Development of the brine migration test for Asse continued, with evaluation of comments on the revised test plan and continuation of preliminary design of the test hardware.

Waste-Rock Interaction

Technical concerns with the preliminary test concepts developed for this task resulted in a decision to delay further test planning. In the interim, the effort was redirected to develop a basis to respond to these technical concerns through systematic reviews of the issues and test programs (laboratory or field) relevant to waste-rock interactions in salt. This effort was completed, and a document summarizing the conclusions of the reviews and the status of the waste-rock interaction program was begun.

Waste Package Materials

An effort was initiated to evaluate potential tests that could piggy-back on the brine migration test.

ACTIVITIES DURING THE REPORTING PERIOD

Brine Migration

The major events during this quarter were issuance of the Final Test Plan for the brine migration test at Asse, AESD-TME-3095, and completion of the preliminary design of the test hardware.

A thermomechanical analysis of the salt response to operation of the brine migration experiment was completed. This indicated that the heating pulse would cause a compressive stress on the heated test section of about 4,000 psi, which is considerably higher than the lithostatic stress of 2,400 psi. This necessitated a design revision of the test assembly to increase the strength to resist this load. In addition, a growth of the salt adjacent to the test assembly toward the mine opening of 4 cm in the two-year test interval was calculated. However, gaps between the upper test assembly and the salt will accommodate this growth without excessive loads being transmitted to the test assembly.

The agreement to conduct the brine migration test at the Asse Mine has been formalized. Original plans were to conduct two tests in the "pure" salt layer and two other tests in the adjacent "transition" salt layer. However, water content determinations at the test site indicated that the pure salt has too low of a water content (less than 0.03 weight percent), so it was decided to conduct all four tests in the transition salt. The Germans described the results of the preliminary design of the handling system for the radioactive source which were as anticipated. Other design details were defined.

Evaluation of the acceptability of alumina beads to fill the gap between the test assembly sleeve and the salt wall is proceeding. Preliminary results show that the beads have sufficient strength and that they will not react with brine or water vapor excessively.

Waste-Rock Interaction

The quarter was largely devoted to the writing of a topical report covering the status of completed work on the field test concepts developed for waste-rock interaction. Major objectives of this report were to provide the project with rational objectives for waste-rock interaction field tests in salt and to place the respective roles of laboratory testing and field testing for the study of waste-rock interaction in perspective. The draft report on the status of waste-rock field testing in salt contains the conclusions of a limited thermomechanical analysis of test hole behavior completed by D'Appolonia.

Waste Package Materials

A draft report about potential add-on tests for the brine migration test gives initial descriptions of three add-on tests to evaluate uncertainties in the waste package conceptual designs. The three test areas involve materials tests, backfill tests (including an evaluation of crushing loads), and thermomechanical model evaluation.

FUTURE ACTIVITIES

Brine Migration

The verification tests will be completed.

Waste-Rock Interaction

Review and planning support will be available while the field test programs are further evaluated.

Waste Package Materials

Work will be initiated in FY 82 to add sensors to the brine migration test to measure the stress imposed by the salt on the test assembly heated section.

REFERENCE

Westinghouse Electric Corporation Advanced Energy Systems Division, 1981. Brine Migration Test for Asse Mine, Federal Republic of Germany, Final Test Plan, AESD-TME-3095, Pittsburgh, PA.

WBS 1.4.2

PROJECT: Crystalline Rock Mining Technology

PRINCIPAL INVESTIGATOR: Colorado School of Mines (W. Hustrulid)

ONWI PROJECT MANAGER: W. F. Ubbes

OBJECTIVE

The Colorado School of Mines has established a research facility at its Experimental Mine located at Idaho Springs, Colorado, to develop excavation techniques and site evaluation procedures appropriate for the location, design, construction, licensing, and long-term monitoring of a hard rock nuclear waste repository. In the experimental room, a large (2 x 2 x 2-meter) block isolated from the surrounding rock by line drilling can be loaded both thermally and mechanically. These studies will furnish basic data regarding jointed rock behavior under a variety of simulated repository conditions. The block will also provide a site for equipment development and calibration.

ACTIVITIES DURING THE REPORTING PERIOD

No progress report was submitted for the period.

WBS 1.4.3

PROJECT: NWTS Repository Equipment Development Plan

PRINCIPAL INVESTIGATOR: Battelle Columbus Laboratories (T. M. Trainer)

ONWI PROJECT MANAGER: N. C. Henderson

OBJECTIVE

The objectives for FY 81 and FY 82 are (1) to modify the Technology Development Plan for NWTS Repository Equipment in accord with Repository-IWG and DOE recommendations, (2) to prepare a draft Repository Equipment Test Plan, and (3) to assist the ONWI staff in preparing statements of work in accord with the Technology Development Plan.

PROGRESS REPORTED PREVIOUSLY

Work during the first quarter consisted of (1) a review of available information pertinent to repository equipment testing and further definition of the purposes of the Repository Equipment Test Plan, and (2) the preparation of two draft statements of work on a study of equipment alternatives for the subsurface handling of canistered nuclear waste, and a reliability and maintainability analysis of a canistered waste handling system for a nuclear geologic repository.

During the second quarter, the following task activities were accomplished: (1) an outline for the test plan was developed and the introduction and first four sections were drafted; and (2) a statement of work was drafted on an investigation of emplacement hole drilling equipment and procedures, an outline was developed for a reliability and maintainability plan for repository HLW handling equipment, and position papers were prepared on the NWTS plan for the use of codes and standards in the design of geologic repository equipment, and the NWTS plan for the application of as low as reasonably achievable (ALARA) radiation exposure requirements to the design of repository equipment.

ACTIVITIES DURING THE REPORTING PERIOD

Work during the third quarter of FY 81 resulted in the following accomplishments on the three project tasks.

Revision of the Technology Development Plan for NWTS Repository Equipment

A detailed review was made of the planned technology development activities in response to recent ONWI planning for the Test and Evaluation Facility and the first geologic repository. Several needed changes were identified.

Preparation of a Draft Repository Equipment Test Plan

Considerable effort was spent on the examination of possible waste handling equipment testing for the Test and Evaluation Facility (TEF). Attention was also given to the impact of the Test and Evaluation Facility on equipment testing schedules for the first geologic repository.

Preparation of Draft Statements of Work for Equipment Technology Development

A prerequisition plan was drafted for the design, fabrication, and acceptance testing of TEF waste handling equipment.

WBS 1.4.4

PROJECT: Directional Antenna

PRINCIPAL INVESTIGATOR: Lawrence Livermore National Laboratory (M. Buettner)

ONWI PROJECT MANAGER: A. Andrews

OBJECTIVE

The overall objective is to construct a directional antenna system, usable within a single borehole, for locating anomalies near the borehole. The goals are to:

- Show experimentally that miniature, directional antennas can be produced by enclosing the antenna elements in a sheath made of a ferrite or ferroelectric material
- Provide an assessment of the most appropriate sheath materials.

Such a probe would enable the assessment of potential waste repository sites in salt for anomalous features such as fractures and brine or gas-filled pockets using a minimum number of boreholes.

PROGRESS REPORTED PREVIOUSLY

This project began in January 1980. The major technical accomplishment has been to produce a prototype probe, probably the first of its kind, that is directional in the frequency range 190 to 250 MHz and can be placed into a 4-inch borehole.

Related technical accomplishments are the writing of a two-dimensional computer code to predict the radiation pattern of the probe and determination of the complex permeability (μ^*) and permittivity (ϵ^*) for the ferrite used to construct the directional probe.

ACTIVITIES DURING THE REPORTING PERIOD

The key technical activities fall into two major areas. The first is characterization and modeling of the directional probe, and the second is determination of an optimum system and predicting its performance.

Characterization and Modeling for the Directional Probe

Antenna pattern measurements using the directional probe were made, and comparison of these results with predictions of the two-dimensional computer model mentioned previously reveals that the computer model predictions are of limited value when applied to actual, three-dimensional antenna structures.

Accordingly, a computer code based on a three-dimensional model of the antenna has been written and is being debugged by considering progressively more taxing test cases.

Predicting System Performance

System performance has been predicted from the approach that the complete system, including electronics, antennas, geologic medium, and anomalies, must be modeled. A computer code, System Performance Code, was written to model the problem at hand. The code is modular so that each subsystem, e.g., the geologic medium, can be treated separately. As presently constituted, the code models an arbitrary input signal to the directional probe and follows its progress through the medium, after reflection from an anomaly, and back through the medium to a receiving antenna.

Two models for the anomaly are now being used: a perfectly conducting plane and a finite-thickness, planar layer of arbitrary properties. The code is now being debugged.

FUTURE ACTIVITIES

The following activities are planned:

- Determination of ϵ^* for salt samples will take place. Knowledge of ϵ^* will permit an estimate of the radar range in salt.
- Debugging the System Performance Code will continue on a limited basis.

WBS 1.4.4

PROJECT: Monitor for Detecting Nuclear Waste Leakage in a Subsurface Repository

PRINCIPAL INVESTIGATOR: Lawrence Berkeley Laboratory (S. Klainer)

ONWI PROJECT MANAGER: N. C. Henderson

OBJECTIVE

A new ultrasensitive analytical technique, based on the laser-induced fluorescence fluorimetry (LIFF) technique, allows quantitative measurements of actinide, lanthanide, and tracer abundances in water samples with sensitivities many orders of magnitude higher than presently achieved with current analytical methods. The principal focus of the present program is to develop monitoring instrumentation for those elements in ground waters associated with nuclear waste repositories.

The monitoring system provides for two modes of analysis: (1) an in situ system which provides direct chemical measurements in natural water systems over long distances (>1 km) using fiber optics, and (2) the field laboratory system which is far more sensitive and involves (on site) LIFF measurements on these materials after they have been coprecipitated (from ground-water samples) with an inorganic material such as calcium fluoride.

PROGRESS REPORTED PREVIOUSLY

This project began 1 April, 1980. A versatile laboratory fluorimeter (fluorescence spectrometer) has been assembled which is capable of making measurements using both the fiber optic (remote) technique and the coprecipitation (high sensitivity) method. Proof of principle for the remote fluorescence measurements has been made at 0.2 km using fluorescent tracers and communication-grade fiber optics coupled to a laboratory fluorimeter. In situ tracer measurements to 10^{-9}M (0.2 ppb) can be made with the present equipment. Initial results, using coprecipitation, have demonstrated lanthanide sensitivities of 10^{-6} ppb and uranium sensitivities below 2×10^{-6} ppb (0.002 ppt). The projected plutonium sensitivity is of the same order of magnitude or lower. Crystals of $LaCl_3$ doped with plutonium, which were analyzed using a nitrogen dye laser (at 77 K), resulted in a deep-red fluorescence at two separate sharp absorption bands. A new instrument using optical filters has been constructed that is expected to allow the detection of actinide element concentrations as low as 10^{-18}M.

ACTIVITIES DURING THE REPORTING PERIOD

Remote Fiber Fluorimetry (RFF)

Optrode Studies. Remote fiber fluorimetry provides direct chemical measurements of ions, compounds, and tracers in natural water systems over long distances using fiber optics and optrodes. A fiber optical sensor probe, or optrode, is chemically specific and behaves much as an ion-specific electrode. The most promising optrode design to date is the capillary optrode. A new miniature lens has been developed to couple the laser light into a capillary tube. The new lens reduces the optical aberration experienced in earlier spherical lenses and increases the effective optical sensitivities. New methods of silver-plating and coating the inside surfaces of the capillary tubes and end plates are being studied.

Repository Mockup Tank. A 55-gallon drum filled with sand and fitted with ports to insert optrodes and optical fibers has been constructed and located some distance from the analytical laboratory. Ion-specific optrodes will be inserted into the drum ports, and solution ions (UO_2^{++}, Sm^{3+}, and Eu^{3+}) and tracer materials will be percolated through the system to simulate field conditions.

Uranyl Ions in Solutions. The lower detectability limit of UO_2^{++} ions in aqueous solutions has been reduced to 10^{-5} M and is at present limited by the short half-life of the uranyl ion fluorescence (< μ5 s). The new tunable pulsed dye laser system along with more compatible ultraviolet optical fibers should enhance the UO_2^{++} signal-to-noise ratio and lower the limits of detectability.

Coprecipitation-Enhanced Fluorimetry (CEF)

Plutonium Studies. This procedure consists of an initial coprecipitation of solution actinides with a suitable carrier. The actinide is monitored using laser-induced fluorescence fluorimetry on the solid precipitates. The carrier is usually a transparent host crystal material at the excitation and fluorescence wavelength of interest. A number of new host crystals for plutonium have been studied. In a few cases, small amounts of terbium have been coprecipitated along with the plutonium and host material. These samples are excited at the plutonium absorption wavelength and the terbium fluorescence is monitored for energy transfer. None of the host materials studied so far are as sensitive as $LaCl_3$ for detecting plutonium. New methods for producing $LaCl_3$:Pu(III) samples are being considered.

Americium. Americium samples have been prepared with a number of host crystal materials. The americium fluorescence studies will proceed along with the plutonium studies.

Field Spectrometer. Initial testing on the high-sensitivity field spectrometer, which uses optical filters, indicates reproducibilities in the range of 2 to 3 percent.

FUTURE ACTIVITIES

The following activities are for the next quarter:

1. Start analyzing americium samples
2. Continue searching for a sensitive host crystal for plutonium
3. Determine the lower limits of detectability for Pu^{3+} in $LaCl_3$ crystals
4. Upgrade the high resolution pumped dye laser and cryogenic system for isotope studies
5. Collect and analyze water samples from a contaminated ground-water area
6. Continue the development of ion-specific optrodes
7. Use the laboratory's nanosecond pulsed dye laser to study UO_2^{++}, Sm^{3+}, and Eu^{3+} ions and tracers under field-simulated conditions.

WBS 1.4.4

PROJECT: Nuclear Quadrupole Resonance (NQR) Techniques to Measure Stress and Strain in Rocks

PRINCIPAL INVESTIGATOR: Lawrence Berkeley Laboratory (S. M. Klainer)

ONWI PROJECT MANAGER: N. C. Henderson

OBJECTIVE

The goal of this project is to develop a new technique to measure underground stress. The measurement of the in situ state of stress in rocks must be known to ensure the integrity and safety of underground openings. Present stress measurement techniques are costly, time-consuming, often unrepeatable, and difficult to carry out. This program uses the microscopic response of crystalline materials to stress, particularly changes in the chemical bonds that increase the electric field gradient (EFG) tensor. The EFG is observed using nuclear quadrupole resonance (NQR) or a double resonance technique involving NQR and nuclear magnetic resonance (NMR). The stress tensor can be determined from the NQR frequencies observed in the rocks surrounding a borehole.

The first phase of the project is focused on stress measurements in rock salt, and later aluminum-containing minerals will be investigated. Faster and more reliable stress measurements will be valuable in the site-selection process leading to an underground nuclear waste repository.

ACTIVITIES DURING THE REPORTING PERIOD

No progress report was submitted for the period.

WBS 1.4.4

PROJECT: Stress Displacement Measurement Techniques

PRINCIPAL INVESTIGATOR: Terra Tek, Inc. (R. Lingle)

ONWI PROJECT MANAGER: M. M. Lemcoe

OBJECTIVE

The licensing of underground repositories for the disposal of nuclear waste requires that the computational methods used to calculate the thermomechanical response of the repository and surrounding host rock to heat generated by the nuclear waste be experimentally validated. Experimental validation, in general, requires in situ testing of repository components such as pillars. For certain applications, the test instrumentation must exhibit long-term stability in an adverse temperature environment. This instrument development program involves the modification of existing techniques or, if necessary, the development of new techniques for in situ measurement of stresses and deformation in rock salt and hard rock.

ACTIVITIES DURING THE REPORTING PERIOD

No progress report was submitted for the period.

WBS 1.4.5

PROJECT: Repository Sealing Project

PRINCIPAL INVESTIGATOR: D'Appolonia Consulting Engineers, Inc. (D. E. Stephenson)

ONWI PROJECT MANAGER: F. L. Burns

OBJECTIVE

The primary objectives of the penetration sealing program are (1) to develop seal designs to fulfill the design goals of providing safe seals at a resonable cost, (2) to provide seal designs on schedule to satisfy overall repository licensing requirements, and (3) to provide coordination and interfacing with the other ongoing repository sealing studies being performed in the laboratory and at ONWI field sites.

PROGRESS REPORTED PREVIOUSLY

This project was initiated on 6 November, 1978. The following reports have been issued:

• ONWI-3	Development of Plan and Approach for Borehole Plugging Field Testing
• ONWI-15	The Status of Borehole Plugging and and Shaft Sealing for Geologic Isolation of Radioactive Waste
• ONWI-55	A Repository Sealing Design Approach--1979
• ONWI-90	An Evaluation of Generic Similarities and Differences in Requirements for Sealing Shafts, Tunnels and Boreholes
• ONWI-108	Repository Sealing: Evaluation of Materials Research Objectives and Requirements--1980.

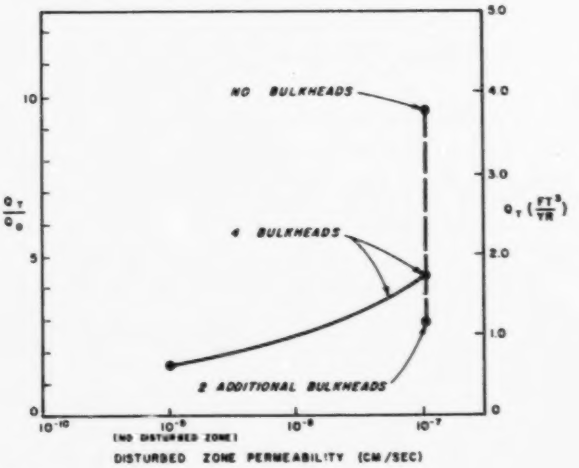
ACTIVITIES DURING THE REPORTING PERIOD

A schematic design for penetration seals in bedded salt, referenced to the Los Medaños Site in New Mexico, was described previously. Progress with this design has been to continue numerical modeling of seal performance and to more closely define data requirements. Figure 1 shows results from a total flow analysis of the shaft seal system, including backfill and bulkhead components. The model presumed a steady state flow with the permeants injected at the bottom of the shaft seal and released to the biosphere at the top of the salt formation. An axisymmetric model with no flow boundaries at 36-foot (11 m) radius has been used for a 6-foot (1.8 m) radius shaft. The distributed zone extends to a radius of 12 feet. The bulkheads are presumed to totally replace the disturbed zone. Figure 1 shows results for a 100-foot driving head, indicating a flow rate in the range 0.5 to 1.5 ft^3/year (14 to 42 liters/year) for the base case with four bulkheads. This flow would be 1.5 to 4 times the flow through an undisturbed host rock with a 36-foot radius and the same driving head. Further analyses indicate that for the case of high (10^{-7} cm/sec) disturbed zone permeability, removal of bulkheads can significantly increase the flow potential. However, additional of two more bulkheads does not greatly reduce the flow potential.

The average water particle transit time through the same model has been estimated to be approximately 60,000 years, assuming that the flow is occurring through a porous medium. This result is under further evaluation, particularly with regard to accounting for sorption, dispersion, and the presence of fractured media.

A report about sealing considerations for repository shafts in both bedded and domal salt reviews the geology and hydrology of Los Medaños and of the candidate NWTS dome salt sites, and identifies key sealing locations related to the stratigraphy and significant water-bearing zones. For Los Medaños, these key seal locations are incorporated in the schematic design. Key sealing locations (related to site hydrology) for Richton Dome, Mississippi, are shown on Figure 2. In both cases, seals located in the shaft will be critical to prevent or retard water inflow into the repository. Shaft seals, however, form only part of a complete shaft-tunnel sealing system that will perform the dual function of limiting both radionuclide release and water inflow. The report also includes a review of experience gained from construction and operation of shafts at conventional mines in the Carlsbad, New Mexico, potash mining district and the Gulf region salt mines.

The application to repository sealing of two candidate seal materials, clay and polymer concrete, has been reviewed. Compacted clay (in general) is a well-chosen candidate seal material with favorable properties of low permeability and relatively high sorptivity. Further testing, particularly with model seals, is required to compare the advantages and disadvantages of swelling and nonswelling clays.



NOTES

1. Q_T = Total Flow through 36 Feet Radius Seal Zone
2. Q_O = Flow through 36 Feet Radius of Undisturbed Rock

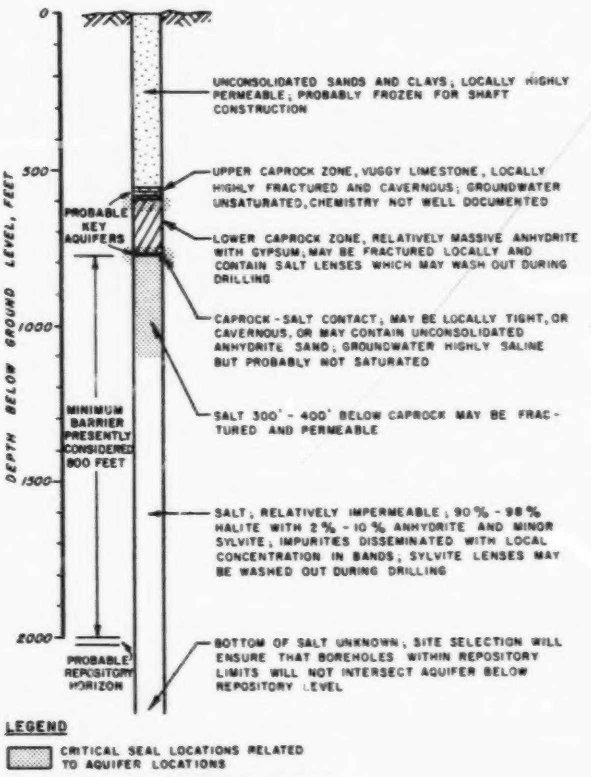
ASSUMPTIONS

1. Model Height - 1250 Feet (380 Meters); Model Boundary Radius - 36 Feet (11 Meters); Shaft Seal Radius - 6 Feet (1.8 Meters); Disturbed Zone Radius - 12 Feet (3.7 Meters)
2. Hydraulic Driving Head - 100 Feet (30.5 Meters); Steady State - Saturated
3. Number of Bulkheads - 4 (Cut Off Disturbed Zone)
4. Material Properties

	K(cm/sec)
Host Rock - Salt	10^{-9}
Disturbed Zone	10^{-8}
Anhydrite	10^{-9}
Concrete/Gravel Grout	10^{-9}
Earth Fill	10^{-7}

5. Impervious Boundary Condition (No Flow across Lateral Boundaries)

Figure 1. Flow Through the Shaft Seal Zone.



0
500
1000
1500
2000
DEPTH BELOW GROUND LEVEL, FEET
UNCONSOLIDATED SANDS AND CLAYS; LOCALLY HIGHLY PERMEABLE; PROBABLY FROZEN FOR SHAFT CONSTRUCTION
UPPER CAPROCK ZONE, VUGGY LIMESTONE, LOCALLY HIGHLY FRACTURED AND CAVERNOUS; GROUNDWATER UNSATURATED, CHEMISTRY NOT WELL DOCUMENTED
PROBABLE KEY AQUIFERS
LOWER CAPROCK ZONE, RELATIVELY MASSIVE ANHYDRITE WITH GYPSUM; MAY BE FRACTURED LOCALLY AND CONTAIN SALT LENSES WHICH MAY WASH OUT DURING DRILLING
CAPROCK - SALT CONTACT; MAY BE LOCALLY TIGHT, OR CAVERNOUS, OR MAY CONTAIN UNCONSOLIDATED ANHYDRITE SAND; GROUNDWATER HIGHLY SALINE BUT PROBABLY NOT SATURATED
MINIMUM BARRIER PRESENTLY CONSIDERED 800 FEET
SALT 300' - 400' BELOW CAPROCK MAY BE FRACTURED AND PERMEABLE
SALT; RELATIVELY IMPERMEABLE; 90% - 98% HALITE WITH 2% - 10% ANHYDRITE AND MINOR SYLVITE; IMPURITIES DISSEMINATED WITH LOCAL CONCENTRATION IN BANDS; SYLVITE LENSES MAY BE WASHED OUT DURING DRILLING
PROBABLE REPOSITORY HORIZON
BOTTOM OF SALT UNKNOWN; SITE SELECTION WILL ENSURE THAT BOREHOLES WITHIN REPOSITORY LIMITS WILL NOT INTERSECT AQUIFER BELOW REPOSITORY LEVEL
LEGEND
CRITICAL SEAL LOCATIONS RELATED TO AQUIFER LOCATIONS

Stratigraphy based on Richton Dome, Mississippi. Other domes have the same stratigraphic units but overburden and caprock thicknesses vary.

Figure 2. Shaft Sealing Considerations Related to Stratigraphy--Salt Dome Site.

Priority should be given to establishing seal-rock interface performance and characterizing the physiochemical changes occurring in that area. Additionally, clay seal performance must be established under the cyclic temperature and wetting and drying conditions that may occur in a repository environment. Polymer concrete is a promising seal material that may be useful in areas where high temperature prevails or where high strength is required. Polymer concrete, however, is not identified as a priority candidate sealing material at this time, primarily because it is not clear that the improved properties of polymer concretes compared with conventional concretes (such as higher compressive strength) are required in penetration seals. Further, polymer concretes are new materials for which no long-term data are available. Since the polymers, themselves, are not stable, it is possible that the performance of polymer concrete may degrade substantially over long time periods. Polymer concretes may also be difficult and/or dangerous to emplace.

A review of studies of the disturbed zone in tunnels and shafts at various sites shows that very few direct measurements of disturbed zone permeability have been made, and that the results obtained are inconclusive. At Strips, the macropermeability test shows a zone of reduced radial permeability surrounding the test tunnel, but no data are available for the zone immediately adjacent to the tunnel wall. At the Colorado School of Mines there is no clear evidence for a disturbed zone in the results for permeability tests in radial boreholes drilled from the excavation; however, there is significant variation in the permeabilities resulting from the fractured nature of the rock mass which may obscure disturbed zone effects. Measurements of disturbance effects using techniques other than permeability testing (e.g., seismic methods, deformation jacks, extensometers) have been made at many sites, but these results are not readily applied to sealing requirements. Clearly, the extent of the disturbed zone depends on how the zone is defined and measured. For example, extensometers might reveal a disturbed zone extending several radii from the excavation, but this does not necessarily imply a significant increase in permeability.

FUTURE ACTIVITIES

Ongoing activities will emphasize a performance assessment of the Los Medaños designs. Schematic designs will be initiated for Hanford basalt and Nevada Test Site tuff. Disturbed zone studies will continue to identify (if possible) general trends from existing data and hence define ways in which disturbance might be reduced by choice of excavation method. Greater emphasis will be given to analytical predictions of disturbed zone characteristics (relating permeability to stress concentrations), and defining a suite of tests that can be used to characterize the disturbed zone on a site-specific basis.

WBS 1.4.5

PROJECT: Borehole Plugging Program

PRINCIPAL INVESTIGATOR: Sandia National Laboratories (C. L. Christensen)

ONWI PROJECT MANAGER: F. L. Burns

OBJECTIVE

The objectives of this program are:

1. To develop, test, and evaluate candidate cementitious grouts and other materials for use in and support of the laboratory and field-testing program; to assist in developing and implementing a geochemical program to ascertain and verify the long-term stability and suitability of cementitious and other materials as wellbore plugging materials.
2. To assess, develop, and modify appropriate instrumentation techniques to obtain the data required to verify plug performance.

PROGRESS REPORTED PREVIOUSLY

The current Borehole Plugging Program (BHP) was initiated in September, 1978, with full-scale operation under way by February, 1979.

The prognosis from previous work indicates that cementitious materials should provide adequate plugs. Their attractiveness stems from the availability of existing technology and their favorable economics of materials and emplacement. One of the valuable results obtained to date shows that push-out strength tests, frequently employed in concrete testing procedures, are inadequate to assess the permeability of the interfaces between the grout and the rock. Heretofore bond strength was considered to be an indicator of plug adequacy. It has been demonstrated that a strong bond does not necessarily result in a low interface permeability.

Additionally, when grouts are tested as plug material in a candidate rock sample, the type of mix water is important. Initial testing of grouts used a brine mix water on the assumption that these plugs, when emplaced in a salt formation in a brine-filled wellbore, would result in a better bond to the formation. However, when these mixes were cast in the anhydrite rock samples of the Bell Canyon Test (BCT) plug zone, higher-than-expected permeabilities occurred at the interface due to a salt residue resulting from the cement hydration. A change to a fresh-water mix alleviated this effect and was used in the plug mix currently in place in the BCT.

While results are still being evaluated, indications are that, in nonsalt emplacements, the impact of brine mix water must be carefully assessed. Testing of this hypothesis continues at the U.S. Army Corps of Engineers WES, Vicksburg, MS. This testing is directed at determining the acceptable salinity that should be permitted in a given plugging application.

ACTIVITIES DURING THE REPORTING PERIOD

The *Bell Canyon Test Summary Report* was published (SAND80-1375). The preliminary laboratory setup has been established for salt precipitation experiments from brine, and initial feasibility has been demonstrated. Work continues to refine the temperature/flow parameters required in the process to obtain industrial consistency.

WBS 1.4.5

PROJECT: Seal Materials Selection and Longevity

PRINCIPAL INVESTIGATOR: Pennsylvania State University (D. M. Roy)

ONWI PROJECT MANAGER: F. L. Burns

OBJECTIVE

Any method chosen or developed to dispose of radioactive waste in the geologic environment will require various degrees of penetration of the medium with borehole, shafts, and tunnels. To ensure isolation of the wastes from the biosphere, such penetrations must be adequately sealed for extended periods of time. This program is focusing on those physiochemical and thermodynamic properties of seal materials which impact both seal-host-environment compatibility and long-term geochemical stability, culminating in seal material characterization and selection on a site-specific basis.

Prior to FY 81, these studies concentrated on using portland cement-based materials and composites, with particular emphasis on their application to borehole plugging in conjunction with generic host materials. This effort has been expanded to include clay-clay composites and other alternative materials. A broader range of general host conditions and materials will be considered, along with site-specific horizons as they develop.

PROGRESS REPORTED PREVIOUSLY

The research has been carried on in two phases: (1) materials selection and evaluation, and (2) geochemical, long-term stability.

Materials Selection and Evaluation

In order to design cementitious materials to meet the criterion of an effective repository seal, the effects of composition, chemical additives, particle size, etc., must be established. Currently a range of commercially available cements, modified by the addition of reactive materials including fly ash, slag, ferrosilicon dust, and fine quartz and adjusted by various admixtures to further provide desirable handling and placement, are being studied under various water-to-cement ratios and curing conditions. Property determinations considered important to their evaluation as a plug-seal material include viscosity, compressive strength, permeability, volume change, bond strength, and heat of hydration. A review of the physical, chemical, and mechanical properties of clay-clay composites, as well as those of zeolites, continues as part of a preliminary evaluation of their role as seal materials and composites.

Geochemical Stability Studies

Concurrent with materials selection and evaluation, factors influencing performance and long-term stability are being examined to serve both as guidelines for further materials selection and to provide an evaluation of those which have shown desirable physical and mechanical properties. Calculations of the cement phase reaction products for which no thermodynamic data are available are in progress. Some phase-pure materials were synthesized for precise confirmatory thermodynamic property determinations. These studies continue to be supplemented by detailed analyses of selected ancient and old human-formulated building materials.

ACTIVITIES DURING THE REPORTING PERIOD

Materials Selection and Evaluation

Cement-Based Materials. During the past quarter, considerable progress has been made in evaluating various mortar mixes for sealing purposes. These fluid mortars could be used as grouts or as matrix in preplaced aggregate concrete.

Based on their ability to convert excess calcium hydroxide to carbon-sulfur-hydrogen material, the components found most reactive were various fine-grained amorphous silica products, while the fly ashes were less reactive. It was found that the amorphous silica products resulted in greater early strength (>100 MPa at 7 to 14 days). To achieve what is felt to be greater long-term stability, additional formulations using combinations of the more reactive components with fly ash and slag have been made up for both long- and short-term experiments. These have been designed to retain the desirable rheological properties and low permeabilities and exhibit moderate expansion through inclusion of additional sulfate in the starting mix, leading to the formation of ettringite as a volume control mechanism. Samples for both long- and short-term testing have been made up and subjected to various curing times and temperatures. Testing will continue through the next quarter.

Clay and Clay Composites. The past quarter has been spent on the review and analysis of existing data, with emphasis on clay mineral stability under anticipated repository sealing conditions. Virtually all prior studies emphasize the highly favorable permeability and cation exchange capacity associated with smectite clays with little or no consideration of long-term stability, with the assumption that smectite will persist as a fully hydrated, highly adsorptive phase for the life of the repository.

Results from kinetic studies on the transformation of smectite to illite suggest that under repository conditions smectite may not remain stable and that significant illitization could occur resulting in a mixed illite-smectite layer. The most obvious implications of this transformation are the modification of the desirable properties of water adsorption and cation exchange.

Zeolites. As a component of composite shaft-sealing materials, the alteration of zeolites under repository conditions is being investigated. Hydrothermal treatment of seven zeolites and three clay minerals in NaCl brine (similar to WIPP-B), high-magnesium brine, and high-calcium brine under confining pressures up to 30 MPa and temperatures of 200 and 300 C for 28 days has been completed. Alteration products are being studied by X-ray diffraction. Solution phases of the reaction products were separated, and the elements silicon and aluminum were analyzed by atomic emission spectrometry. Solution results indicate the release of greater aluminum in the presence of the magnesium brine than in the presence of NaCl brine. No significant amount of silicon was released with any of the brine.

Geochemical Long-Term Stability

Stable Cement and Concrete. Progress has been made on the study of the interfacial region of cement-rock composites. Work completed during the quarter includes the preparation of samples using both generic and site-specific rock types in conjunction with the PSU-WES mix. Concurrently, a literature review and update of surface phenomena related to cement clinker have been completed in addition to a comparison of surface study techniques applicable to cement systems.

Thermodynamic Properties. The effect of groundwater intrusion upon the potential stability of repository seal materials is being examined from thermodynamic considerations. Formation of the calcium chloroaluminate hydrate, Friedel's salt, is thermodynamically favored, in the presence of either minimal or excess water. Although the free energy of reaction to form the chloroaluminate phase is less negative in typical silicate ground waters than in the presence of brine, the phase is still very stable. Ettringite also is thermodynamically stable in equilibrium with both ground waters, with its rate of formation enhanced in the saline water compared to in the silicate water.

Ancient Concrete. Laboratory studies of the ancient human-made building materials collected in

Italy, Greece, and Cyprus are continuing. Macroscopic hand specimen descriptions have been completed. The matrix fraction has been separated from the aggregate fraction for each sample, and X-ray diffraction analyses of both have been completed. Thermogravimetric data have been collected for the matrix fractions and for selected aggregate materials. Chemical analyses are under way and will be completed during the next month. Previously prepared thin sections and scanning electron microscope (SEM) samples are being examined for SEM characterization.

FUTURE ACTIVITIES

Physical property determinations of existing long-term and short-term grout, mortar, and concrete samples will continue. Experimental studies related to the Los Medaños bedded salt will be completed, and a related topical report will be prepared. Preliminary evaluation of clay-clay composites will be completed and reported. Analysis of data obtained subsequent to publication of the PSU-WES Interlaboratory Methodology Study (ONWI-198) will be completed and prepared as a follow-up report.

REFERENCE

Roy, D. M., M. W. Grutzeck, and K. Mather, 1980. PSU/WES Interlaboratory Comparative Methodology Study of an Experimental Cementitious Repository Seal Material, ONWI-198, Office of Nuclear Waste Isolation, Battelle Memorial Institute, Columbus, OH.

WBS 1.4.5

PROJECT: Seal Materials Performance Limits and Longevity

PRINCIPAL INVESTIGATOR: Corps of Engineers, Waterways Experiment Station (K. Mather)

ONWI PROJECT MANAGER: F. L. Burns

OBJECTIVE

The Structures Laboratory will optimize proportions and materials for grouts and concretes to be used in tests to be made at the Los Medaños site and other sites, using cements, pozzolans, and admixtures with fresh water or water containing salts appropriate to render the grout or concrete compatible with significant properties of the wall rock. Expansive substances produced in grout hydration will be studied to determine the temperature range in which they can be produced and stabilized. Thermal properties, creep, and elastic and strain properties of host rocks and grouts will be investigated. Field surveillance and testing will be provided, and long-time tests of grout will be continued.

PROGRESS REPORTED PREVIOUSLY

Work began on 2 January, 1980. Specimens were cast in the task of optimizing BCT-1FF grout used in the Bell Canyon Test. The joint PSU-WES experiment to develop precision and accuracy data began.

Examinations of ERDA-10 grouts and one- and two-year-old Bell Canyon Test grouts were made. Dynamic and compressive strength tests of those grouts and of two series made in FY 80 were continued.

ACTIVITIES DURING THE REPORTING PERIOD

During the period, five activities took place:

1. Tests of four high-sulfate-resistant Class H cements were completed.
2. Examinations made of five laboratory grouts about four years old and of grouts from two Bell Canyon Test plugs were completed.
3. Structures Laboratory work Memorandum 81-21 on cracking in grout specimens during storage was issued; the purpose is to identify the conditions under which specimens crack in storage, and why.
4. Tests of six plasters and one plaster retarder were made.
5. Chemical dissolution tests of fly ashes were continued.

Four Class H high-sulfate-resistant oil well cements were tested that should be suitable for use in repository sealing. These represent all the sources of this cement in this country.

Standard physical and chemical tests were used for materials characterization. X-ray diffraction (XRD), X-ray emission spectroscopy, light microscopy, differential thermal analysis (DTA), and scanning electron microscopy (SEM) were used as needed for these characterizations. Several sources of satisfactory cements for grouts were found.

Periodic examination by physical tests, XRD, and SEM of grouts ranging from about one to four years old showed normal phase compositions and microstructures. Storage environments included fresh water, brine, temperatures to about 130 F, and dry storage. Studies of these grouts indicate suitable stability which is expected to be long term.

Tests of plasters served to characterize them by chemical, physical, and petrographic properties. It was found that the alpha and beta forms of plaster could be recognized by light microscopy, SEM, and DTA. Use of the alpha form of plaster was found to be desirable.

Some progress was made with chemical dissolution of fly ash. In general, treatment tends to dissolve both glass and other phases. Dissolving of both glass and other phases in fly ash during chemical treatment needs to be circumvented or a means of separating the data into glass content and other phases is needed.

FUTURE ACTIVITIES

The following activities are planned:

1. Study cracking of grout
2. Plan and start program on ettringite stability
3. Make one-year tests on modifications of BCT-1FF grout and recast some of these mixtures to resolve anomalous data
4. Make one-year tests on the cooperative PSU-WES grout mixture
5. Continue periodic examinations and tests of existing grout mixtures as they age
6. Make triaxial creep tests of anhydrite core from the Los Medaños site.

WBS 1.4.5

PROJECT: Wellbore Damage Zone Determination

PRINCIPAL INVESTIGATOR: Terra Tek, Inc.
(M. D. Voegele)

ONWI PROJECT MANAGER: F. L. Burns

OBJECTIVE

The objective of this program is to obtain experimental data on the wellbore damage zone caused by full-scale drilling operations. The extent and characteristics of the damage zone will be evaluated on five rock types. The drilling will be performed in the Terra Tek Drilling Research Laboratory (DRL) using as close as possible the same drilling parameters, bits, drilling fluids, and fluid pressures as those used in the field, and with the rock sample subjected to in situ environmental conditions. The drilling damage will be assessed by making permeability measurements before and after drilling and by dye-penetrant tests. A full-scale laboratory plug leakage test will also be performed. This effort is in direct support of ONWI's repository sealing program and is interactive with an ONWI borehole plug design contractor conducting concurrent modeling studies.

PROGRESS REPORTED PREVIOUSLY

Five rock types (anhydrite, salt, basalt, tuff, and granite) were selected for tests to assess the extent and nature of drilling-induced damage in 15-1/2-inch-diameter samples using 7-7/8-inch-diameter roller-cone and diamond drill bits.

Laboratory permeability measurements on before-and-after drilled samples and dye-penetrant inspections were initially planned as a means of assessing the damage zone. Early results on the anhydrite showed a large scatter in the permeability of the rock, with no particular correlation with drilling. Dye-penetrant inspections also failed to show the presence of a damaged zone. These results prompted the initiation of microscopic examinations on the anhydrite, which showed the drilling-induced damage zone to be of the order of a few grain dimensions. Microscopic examinations were recommended as a supplement to the other techniques in assessing the damage induced in the remaining rock types.

Flow tests were conducted in a drilled and a drilled and plugged anhydrite sample.

ACTIVITIES DURING THE REPORTING PERIOD

The results from the plug flow test have been analyzed and are in good agreement with the results obtained from the Bell Canyon borehole plug test (Christensen and Peterson, 1980). The dye-penetrant added to the water during the flow test clearly indicated that the flow path was at the cement-rock interface. The theoretical smooth wall aperture (e) was calculated using the following equation:

$$e^3 = \frac{q \cdot 12\mu}{\Delta P/L \cdot \pi d}$$

where

q = measured flow
μ = fluid viscosity
L = length of cement plug
d = diameter of cement plug.

The comparison between the two tests is shown in Figure 1.

Microscopic examinations and physical properties measurements on all rock types used in the drilling tests have been initiated.

FUTURE ACTIVITIES

Physical properties measurements, microscopic examinations, and the draft of the final technical report will be completed.

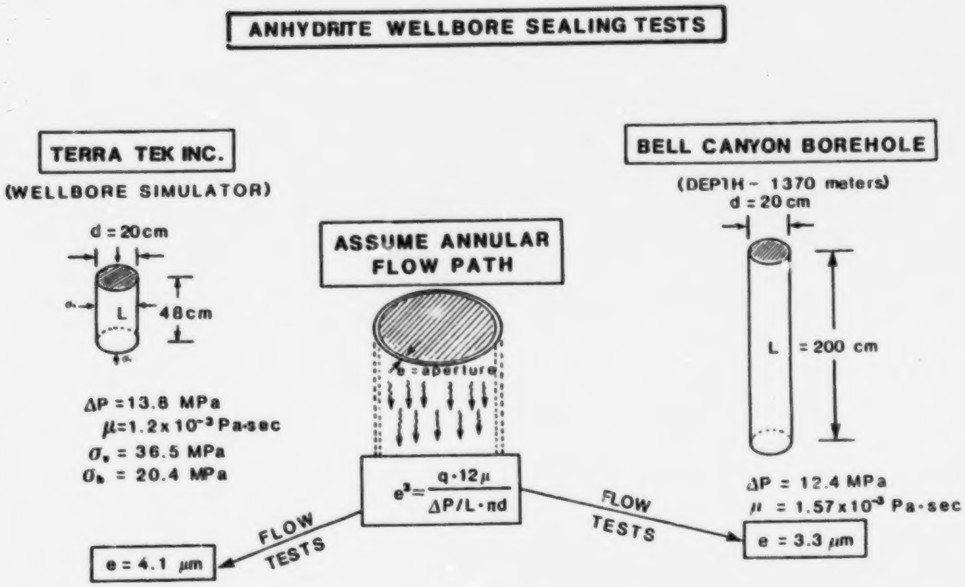

ANHYDRITE WELLBORE SEALING TESTS
TERRA TEK INC.
(WELLBORE SIMULATOR)
d = 20cm
L
48cm
ΔP = 13.8 MPa
μ = 1.2 x 10⁻³ Pa-sec
σᵥ = 36.5 MPa
σₕ = 20.4 MPa
ASSUME ANNULAR FLOW PATH
e = aperture
e³ = q·12μ / ΔP/L·πd
FLOW TESTS
e = 4.1 μm
BELL CANYON BOREHOLE
(DEPTH - 1370 meters)
d = 20 cm
L = 200 cm
ΔP = 12.4 MPa
μ = 1.57x10⁻³ Pa-sec
FLOW TESTS
e = 3.3 μm

Figure 1. Comparison of Plug Flow Test With Borehole Plug Test.

REFERENCE

Christensen, C. L., and E. W. Peterson, 1980. The Bell Canyon Test Summary Report, SAND80-1375, Sandia National Laboratories, Albuquerque, NM.

WBS 1.4.6

PROJECT: Alternate Geologic Media Engineering Studies

PRINCIPAL INVESTIGATOR: Stearns-Roger Services, Inc. (J. C. Mattern)

ONWI PROJECT MANAGER: W. J. Elgin

OBJECTIVE

The primary objective of the Alternate Geologic Media Engineering Studies (AGMES) program is to develop conceptual design guidelines for nuclear waste repositories in selected deep geologic media other than salt. Secondary objectives are: (1) to identify and evaluate other media for further consideration based on engineering feasibility; and (2) to examine and evaluate existing conceptual designs for repositories in deep salt media to assess the changes necessary to adapt the designs to other selected deep media.

PROGRESS REPORTED PREVIOUSLY

The AGMES program was started on 2 February, 1981. The program plan and the QA plan for the entire AGMES program were developed and submitted to ONWI.

The initial work on repository design considerations concentrated on two aspects: a review of the existing conceptual designs for a repository and a study of a series of documents providing design criteria as the primary bases for AGMES design considerations. To understand the established design criteria and identify areas of direct applicability to the AGMES project, a matrix format was adopted for possible use.

ACTIVITIES DURING THE REPORTING PERIOD

Objective

The purpose of the work during this past quarter was to develop general design considerations for a radioactive waste repository in any potential host rock and to initiate the development of a data base of site and media characteristics for welded tuff and basalt rock types. The design considerations will be used later to evaluate and compare different rock types for suitability as a host rock. The data base for tuff and basalt will form the basis of that evaluation for those two rock types.

Procedures

Design considerations have been developed by following several specific steps:

- Existing conceptual repository designs were reviewed, including NWTSR-1 (high-level waste in a dome), NWTSR-2 (spent fuel in bedded salt), CRRD (Conceptual Reference Repository Design), WIPP, and BWIP.
- A list of functional requirements and design criteria was prepared based on review of ONWI, NRC, and EPA documents. Meeting these criteria is the goal of repository design.
- The repository facilities were broken down into divisions and subdivisions in order to systematically identify the different parts of the repository to be designed.
- A list of design considerations for each repository design subdivision was prepared. Design considerations are basically the issues that must be addressed in completing a design which meets the design criteria.
- Description of each design consideration was initiated using a standard format. The descriptions include the items of information needed to address the consideration.

Development of the data base for tuff and basalt was initiated by literature search using the following:

- Computer retrieval with GEOREF, NTIS, and COMPENDEX data bases
- DOE, OWI, ONWI, and NRC publications and bibliographies
- Reference books on rock properties.

A general list of site and media characteristics to be researched was prepared. Tabulations of the characteristics for tuff and basalt were begun and will be expanded as work progresses.

Results and Conclusions

The results of this quarter's work consist of carefully developed lists of preliminary concepts and information. These include lists for the AGMES project on each of the following:

- Functional requirements and design criteria
- Repository divisions and subdivisions, where divisions are the major engineered parts used in a geologic repository
- Master list of design considerations for each division and subdivision
- Site and media characteristics
- Comparative assumptions, which are the technical methods or values assumed for selected design considerations in order to establish meaningful comparisons with existing repository designs and/or to simplify the AGMES technical approach.

The comparative evaluation of alternative geologic media will be performed using the working tools, which are the five lists being developed.

FUTURE ACTIVITIES

During the next quarter, the above items will be finalized and incorporated in a draft report on design considerations. As a result, a basis to identify required repository differences for the alternative media characteristics will be established.

WBS 1.4.6

PROJECT: Technology Development Studies for Geologic Disposal: Effects of Earthquakes on Subsurface Facilities

PRINCIPAL INVESTIGATOR: Savannah River Laboratory (SRL) (I. W. Marine)

ONWI PROJECT MANAGER: M. R. Wigley

OBJECTIVE

The project objective is to evaluate the potential for seismic disruption of underground facilities. The program is divided into the following tasks:

- Review the existing knowledge to document the damage or nondamage to mines, tunnels, wells, and other underground facilities due to earthquakes, and to evaluate the significance of these data (Pratt, Hustrulid, and Stephenson, 1980).
- Perform a detailed mathematical analysis of displacements in the vicinity of faults (Pratt, Zandt, and Bouchon, 1980).
- Through the use of numerical techniques, perform a generic study to determine the effect of an earthquake on underground facilities, with emphasis on how and to what extent seismic waves might affect or create fractures which could permit increased water circulation in the rock surrounding a repository.

ACTIVITIES DURING THE REPORTING PERIOD

The report Numerical Simulations of Earthquake Effects on Tunnels for Generic Nuclear Waste Repositories by Science Applications, Inc. (Wahi, Trent, Maxwell, Pyke, Young, and Ross-Brown, 1980) was published.

The objectives of this generic study were to use numerical modeling techniques to determine under what conditions seismic waves generated by an earthquake might cause instability to an underground opening, or cause fracturing and joint movement that would lead to an increase in the permeability of the rock mass.

Three different rock types (salt, granite, and shale) were considered as host media for the repository located at a depth of 600 m. Special material models were developed to account for the nonlinear material behavior of each rock type. The sensitivity analysis included variations in the in situ stress ratio, joint geometry, pore pressures, and the presence or absence of a fault. Three different sets of earthquake motions were used to excite the rock mass.

The calculations were performed using the STEALTH codes in a three-stage process as follows:

1. An excavation and heating phase to load the model with the correct thermomechanical stress history (quasistatic, involving several years of simulated time).
2. A stabilizing stage to bring the model into equilibrium prior to the earthquake.
3. An earthquake phase (dynamic, with time increments less than a millisecond).

It was concluded that the methodology is suitable for studying the effects of earthquakes on underground openings. In general, the study showed that moderate earthquakes (up to 0.41 g) did not cause instability of the tunnel or major fracturing of the rock mass.

A rock-burst tremor with accelerations up to 0.95 g, however, was found to be amplified around the tunnel, and fracturing occurred as a result of the seismic loading in salt and granite. In shale, even moderate seismic loading resulted in tunnel collapse. Other questions appraised in the study include the stability of granite tunnels under various combinations of joint geometry and in situ stress states, and the overall stability of tunnels in shale subject to the thermomechanical loading conditions anticipated in an underground waste repository.

At the February 11-13 Workshop on Seismic Performance of Underground Facilities, there was a degree of consensus that the tools for evaluating subsurface effects of earthquakes are available and that the next phase should be site-specific data collection and evaluation. Part of that consensus arose because it was generally believed that there are more restrictive design and siting issues than the subsurface effects of earthquakes, that is, static design and thermal loading. The subsurface seismic stresses will be taken care of if these other factors are properly handled.

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WBS 1.4.6

PROJECT: Impact of Defense Waste on Repository Design

PRINCIPAL INVESTIGATOR: Los Alamos Technical Associates, Inc. (R. J. Kingsbury)

ONWI PROJECT MANAGER: M. A. Duffy

OBJECTIVE

The principal objective of this project is to identify the impacts resulting from the receipt and emplacement of defense wastes on two spent fuel repository conceptual designs. High-level waste and transuranic waste are generated by the nation's defense-related programs and may be stored in the geologic repositories to be designed and constructed by ONWI.

ACTIVITIES DURING THE REPORTING PERIOD

No progress report was submitted for the period.

WBS 1.4.8

PROJECT: Fractured Rock Studies Program

PRINCIPAL INVESTIGATOR: Lawrence Berkeley Laboratory

ONWI PROJECT MANAGER: M. R. Wigley

TASK 1: TESTING FACILITIES FOR ULTRA-LARGE ROCK CORES

(D. Watkins)

OBJECTIVE

The principal objectives of the program are: to develop, operate, and maintain a facility for testing ultra-large specimens of rock; and currently, to investigate the hydraulic properties of fractures as they pertain to fluid transport through the rock mass surrounding underground openings. The facility consists of a large triaxial testing machine and associated control, data acquisition, and specimen preparation equipment. The testing machine can accommodate cylindrical specimens, on the order of 1 meter in diameter by 2 meters high, which can be subjected to axial loads up to 17.8 meganewtons and hydrostatic confining pressures of 5.2 MPa. The test facility provides a general capability for testing ultra-large rock specimens for a variety of purposes in support of the research and technology development needs of the Geologic Repository Program of ONWI.

PROGRESS REPORTED PREVIOUSLY

Current research is directed at the effect of specimen size on the hydraulic properties of a single natural fracture in granite. During the last quarter, the second series of steady state radial flow tests was conducted in the subhorizontal fracture of the Charcoal Black Granite specimen, reduced from 0.91 to 0.764 meter in diameter. The rock specimen, particularly the main fracture, was instrumented with LVDTs. Strain gages monitored the solid rock deformation. In five days, 64 flow tests were performed. A typical test involved applying a certain normal load on the specimen and measuring the flow rate as a function of time by injecting water into the borehole located at the central vertical axis of the specimen. Tests were repeated at several steps of axial loading and unloading to study the relationship among fracture conductivity, fracture deformation, and imposed normal stress. The flow rate was monitored during the transient loading and unloading stages as well. On the last day of test, when the axial stress reached 28 MPa, the specimen formed a nearly vertical split. After a few more flow experiments during unloading, the experiment was terminated.

Analysis of data from the first series of flow tests continued. Different statistical analyses, including a deterministic model for estimating the maximum fracture deformation, were introduced to define the relationship between flow rate (cu cm/s/cm head of water) and the average fracture aperture.

A comparison of the flow rate-axial stress relationships of the second and first series of tests revealed that the fracture had opened, probably as a result of the complex operations involved in reducing the specimen from 0.91 to 0.764 meter in diameter. The flow rate continued to decrease exponentially with time during the flow tests.

Due to the structural failure of the rock, further flow tests on this specimen were not feasible.

ACTIVITIES DURING THE REPORTING PERIOD

Data reduction for the first series of flow tests on the natural fracture in the 0.942-meter-diameter Charcoal Black Granite has been completed. Three different procedures were developed to estimate the relationship between average fracture deformation and the imposed axial stress.

All three procedures gave essentially the same relationship between axial stress and average fracture deformation. LVDT data are comparatively more reliable than strain-gage data in estimating fracture deformation. However, the deformation characteristics of the solid rock must be known in order to deduce the fracture deformation from the LVDT data. Since fracture aperture rather than fracture deformation is needed, two approaches were used: (1) statistical analysis of the imposed axial stress versus average fracture deformation to estimate the maximum anticipated closure of the fracture, and (2) curve fitting to extrapolate the curve to complete closure, thus giving an indication of what the initial aperture had been. However, scatter in data points prevented a good curve fit, and the estimate of maximum closure proved to be very sensitive to the statistical procedure employed. Depending on the procedure, the estimate of initial fracture aperture varied from 80 to 190 microns. These results underscore the importance of knowing a priori the initial fracture aperture to define accurately the relationship between hydraulic flow rate and fracture aperture.

Data reduction of the second series of flow tests is in progress. The final stable flow rate was estimated by a form of curve fitting. The maximum unit flow rate for the reduced diameter specimen was 1,077 cu cm/s/MPa of differential pressure at zero imposed normal stress. After several cycles of loading and unloading, unit flow fell as low as 4.5 cu cm/s/MPa at an imposed normal stress of 21 MPa. As observed in the case of the first series of flow tests, the conductivity at a given imposed normal stress decreases with cycles of loading and unloading. This decrease is due to a permanent decrease in fracture aperture as well as to an increase in contact area between the two surfaces of the fracture.

The second series of flow tests gave flow rates much higher than those of the first series for identical normal stresses, as a result of inadvertent disturbance to the fracture during handling and size reduction.

The main horizontal fracture, in which both series of flow tests were conducted, was opened for inspection. Before opening, three guide pins were installed to facilitate reseating. The fracture in the lower block showed the presence of carborundum dust, especially at the outer periphery. The surface also showed a thin deposit of sediment from the water used for the studies. Figure 1 shows the fracture surface on the lower block.

Figure 1. Exposed Surface of Natural Fracture B in 0.764-Meter-Diameter Charcoal Black Granite Specimen.

A dial gage was used to measure the vertical profile of the fracture surfaces, and contour plots were made.

To determine the contact area between the fracture halves, a 0.4-mm-thick lead sheet was inserted, and a 0.07 MPa seating stress was imposed. The indentations on the lead sheet suggested that the contact points were not uniformly distributed, at least at low normal stresses.

The failure of the rock specimen was unexpected since the rock is known to have a compressive strength much higher than the 28 MPa which caused the vertical split. Detailed inspection and subsequent measurements showed that the top surface of the specimen had a somewhat uneven surface with a slight ridge which apparently prevented full contact of the loading platen with the entire area of the top surface. Axial loading introduced tensile stresses on the plane of the surface, and since the rock is generally weaker in tension than in compression, a vertical split had formed parallel and very close to the ridge. It should be noted that the "failure" of the rock specimen was not catastrophic and did not result in loss of load-carrying capacity. However, the specimen was rendered useless for further studies of the effect of size on fracture flow properties.

To get an idea of the strength and deformation characteristics of the rock, compression and indirect tension tests were performed on 5-cm-diameter specimens.

During load tests to check calibration constants of the axial load cells, two of the four full-bridge load cells malfunctioned. It was found that the load cells in question were in electrical contact with the piston. It was thus decided to provide independent power supplies to the load cells. Subsequently, problems were encountered with the cooling system for the hydraulic pump of the axial loading system. Calibration will resume after solving the cooling system problems.

Pilot tests were conducted to evolve a reliable technique to create a clean tension fracture in a solid rock. A satisfactory method is to first inscribe a V-shaped groove, 3 mm wide and 6 mm deep, on the periphery of the rock. Approximately 10 radial holes 18 mm in diameter and 8 cm deep, are then drilled along the groove. Wedges are driven into the holes, making full contact with the walls of the hole. Each wedge is driven with a hammer with a single tap going around the groove repeatedly until a crack forms along the groove. The central borehole can be used to check whether the fracture has permeated the entire cross section.

Conclusions

The two series of flow tests performed on the natural fracture of Charcoal Black Granite revealed that there are gaps in the knowledge of the relationship between hydraulic flow and deformation and stress of a fracture. Since effective stress, rather than total stress, governs the fracture deformation, the distribution of water pressure across the fracture surfaces must be known, and this requires measuring water pressures using pressure transducers. Similarly, precise measurement of initial fracture aperture will help in accurately defining the relationship between flow rate and average fracture aperture. The creation of a carefully controlled fracture in a fully instrumented intact rock specimen should give a much more precise measurement of initial aperture.

FUTURE ACTIVITIES

The following activities for the fourth quarter are proposed to complete the analysis of the second series of flow tests and get the new rock specimen ready for flow tests in the beginning of FY 82:

1. Complete analysis of data for the second series of flow tests.
2. Prepare drafts of reports on the first and second series of flow tests.
3. Complete load cell calibration.
4. Perform compression tests on the 1-meter-diameter solid specimen of Sierra White Granite.
5. Create an artificial fracture in the rock specimen.
6. Install instruments on the specimen, including piezometers to measure water pressure across the fracture plane.

WBS 1.4.8

PROJECT: Stripa Data Analysis

PRINCIPAL INVESTIGATOR: Lawrence Berkeley Laboratory (T. Chan)

ONWI PROJECT MANAGER: M. R. Wigley

OBJECTIVE

The Stripa Data Analysis project has three major components:

1. Thermal and thermomechanical data analysis to understand better the response of a fractured granite rock mass to thermomechanical loading by careful comparison of modeled temperature, displacement, and stress fields with measured data from the Stripa heater tests.
2. Geophysical studies to analyze the various types of remote geophysical measurements at Stripa and compare them with more direct measurements. This analysis will aid in the development and selection of geophysical tools and techniques for future characterization and monitoring of large rock masses.
3. Macropermeability experiments to measure the permeability of a large volume of low-permeability, fractured granite. The primary objective of the experiment is to improve techniques for permeability characterization of large volumes of low-permeability rock for regional groundwater studies.

PROGRESS REPORTED PREVIOUSLY

Thermal and Thermomechanical Analysis

Some sudden temperature changes in the rock around the full-scale heaters were found to occur coincidentally with hydrology tests in the ventilation drift. Finite-element analysis has indicated that the mine openings have only minor effects on the in situ state of stress at the location of the SBH-4 borehole where far-field stress was measured.

Macropermeability Experiment

The experiment began in November 1978, following completion of primary instrumentation. Water influx and pressure gradient measurements were completed at ambient drift air temperatures of approximately 20, 30, and 45 C, followed by a cool-down test back to 20 C. The experiment was continued at each temperature until a reasonable approximation to steady flow conditions was achieved.

Preliminary computations of the average hydraulic conductivity of the rock mass indicated values of 1.0×10^{-10} m/s at 20 C. A decrease in flow rate and an increase in hydraulic head were measured following the temperature increase from 20 to 30 C. This resulted in a decrease of hydraulic conductivity of about 6 percent. This effect was thought to be due to partial closure of fracture flow paths near the drift, from either increased precipitation of dissolved solids within the fractures or thermal expansion of the blocks of intact rock.

Field work concluded on 30 September, 1980, and the data analysis and reporting activities began. Two reports are scheduled for FY 81 to describe the conduct of the macropermeability experiment. These include a presentation of the geohydrological data and a description of the installed equipment and its use.

ACTIVITIES DURING THE REPORTING PERIOD

Thermal and Thermomechanical Analysis

Further cases of coincidental events in the ventilation drift hydrology tests and the heater drift temperature records were found. These support the hypothesis of hydrologic flow paths over the 40 or 50 m separating the two experiments.

Detailed nonlinear finite-element thermal conduction modeling has been undertaken for the two full-scale heater experiments. Comparison of calculated temperatures with thermocouple data shows that (1) at the midplane level there is excellent agreement between field data and temperatures predicted by the conduction model, and (2) measured temperatures are warmer than calculated 1.5 m above the midplane and cooler 1.5 m below. These discrepancies are possibly due to either installation of the heaters slightly above the design positions or air convection in the space between the heater canister and the rock.

A draft final version of a SAC report details numerical estimates of the possible influence of the mine openings on in situ stress.

Several general-purpose finite-element codes, including SAPA, NONSAP, ADINA, and BMINE, were reviewed and found incapable of handling both the temperature- and stress-dependent material properties observed in laboratory tests on Stripa granite specimens. SAP80, a recently developed group of modular, relatively short program segments, can be modified into a special-purpose code for Stripa data analysis and similar geologic nuclear waste storage projects. Significant progress has been made in the code enhancement. A nine-node two-dimensional (2-D) and axisymmetric element with in situ stress capability and temperature- and stress-dependent orthotropic properties has been incorporated into the code. Program verification is under way.

Preliminary 2-D calculations were made of the near-field stress. It was found that the excavation of the computer room and the detailed geometry of the drifts affect the near-field stress by less than 10 percent, but surprisingly the large mine openings, where iron ore has been extracted, have very significant effects on the near-field stress. Figure 1 illustrates that both σ_1 and σ_3, the major and minor principal stresses below the heater drift, can be influenced by as much as a factor of two.

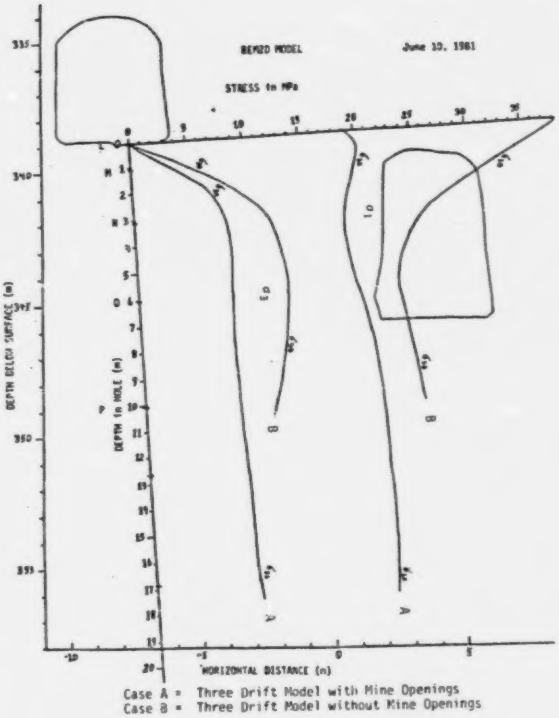

Figure 1. Profiles of Principal Stresses Prior to Heating Along a Nearly Vertical Hole Drilled from the Inversion of the Heater Drift, Illustrating Large Influence of the Mine Openings. Case A = Three Drift Model with Mine Openings; Case B = Three Drift Model without Mine Openings.

Near-field in situ stress has been calculated with a 2-D finite-element elastic-plastic model, using a Drucker-Prager material model with parameters estimated from material properties determined by laboratory testing of intact core specimens of Stripa granite. The results did not differ significantly from those obtained by a linear elastic model.

A nonparametric statistical hypothesis testing technique has been applied to study possible correlation between the displacement data and (1) number of fractures and (2) boundary constraint due to the location of the extensometer in relation to the drifts. Strong correlation was found. Further, comparison of normalized displacements for the 3.6 kW and 5 kW experiments has shown that the in situ thermal expansion coefficient of Stripa granite does increase with temperature, as expected from laboratory testing.

Geophysical Studies

Compilation and readying of the cross-hole ultrasonic data for interpretation has progressed. Almost all of the analog tapes have been read by the digital processing system and are now stored on disk for ready access. The waveforms have been plotted for the hole-to-hole surveys done at equal elevations, and spectral analysis can be done very quickly by fast Fourier transform routines. Consequently, spectra have been computed for many of the hole-to-hole measurements, and RQD (rock quality determination) values have been determined by the spectral ratio technique. A letter report on investigating the geology and thermal stress effects with crosshole ultrasonic seismic measurements in the Stripa heater experiments summarizes the progress made.

A draft on applying borehole geophysics at an experimental waste storage site has been completed. The geophysical logs currently available provide enough resolution to furnish information on an igneous rock mass; zones in both the leptite and the granite can be distinguished by the response of one or more of the ten probes run in SBH-1. The quantification of porosity at the 1 percent level offers a substantial challenge for borehole techniques. Present efforts indicate that the standard methods now used in sediments may be applicable in igneous rock with the proper modifications. The neutron probe has sufficient sensitivity to detect porosity changes of a fraction of 1 percent in a fluid-filled borehole of 76 mm diameter, but the effects of mafic minerals must be accounted for. Similar comments and recommendations for usage of other borehole probes in waste storage applications in hard rock form the content of the report.

Macropermeability Experiment

The final report will be expanded to include a section demonstrating the use of the geohydrologic data in computing the hydraulic conductivity of the rock mass. A second report, dealing with equipment installation and operational analysis, is in preparation.

Preparation of a work plan for data analysis was completed; it includes these primary components:

1. Prepare refined estimates of hydraulic conductivity for the rock surrounding the ventilation drift
2. Compare the macromeasurement of this experiment to the University of Waterloo borehole measurements
3. Undertake two-dimensional discrete fracture modeling of rock around drift to identify parameters controlling water inflow and pressure distribution
4. Study possible causes of low permeability "skin" of rock around drift
5. Conduct miscellaneous studies such as:
   a. Review earth tide data obtained during experiment
   b. Review salt tracer data as point dilation test
   c. Study rock heterogeneity as reflected in water pressure measurements
   d. Apply water pressure data to inverse problem (determining 3-D permeability tensor)
   e. Study effects of experiment on flow into other experimental areas.
6. Prepare model of drift and rock mass to study parameters controlling water inflow and pressure distribution.

FUTURE ACTIVITIES

Thermal and Thermomechanical Activities

Future activities will focus on verifying the 9-node 2-D axisymmetric element by comparison with known closed-form solutions; axisymmetric modeling of one full-scale heater experiment using measured temperature- and stress-dependent material properties; building of a Plexiglas model to aid in construction of a 3-D finite-element mesh; constructing a 3-D mesh and calculating the near-field preheating state of stress in the vicinity of the heater and extensometer drifts; and initiating work on an equivalent medium model of the fractured rock mass.

Geophysical Studies

The report on application of borehole geophysics at an experimental waste storage site will be finalized for publication.

Macropermeability Experiment

The geohydrological data report will be completed for publication, and work will continue on the equipment installation and operational analysis report.

WBS 1.4.8

PROJECT: Material Properties Testing and Analysis

PRINCIPAL INVESTIGATOR: RE/SPEC, Inc.
(A. F. Fossum and G. D. Callahan, Coordinators)

ONWI PROJECT MANAGER: M. R. Wigley

TASK 1: THERMO/MECHANICAL/HYDROLOGICAL ANALYSIS
(G. D. Callahan and A. F. Fossum)

OBJECTIVE

The objective of this program is to assess the thermomechanical behavior and constraints of repository situations in representative geologic formations by numerical analysis procedures (involving the canister scale, room scale, and repository scale regions) and by data from appropriate laboratory testing, laboratory bench scale testing, and in situ experiments. The resulting work efforts address and attempt to answer particular problems relative to the Rock Mechanics Program of the NWTS program.

PROGRESS REPORTED PREVIOUSLY

This program was initiated on 1 October, 1978.

Room Scale Investigations

A three-dimensional (3-D) room scale thermomechanical analysis of a spent fuel repository in salt was initiated. A two-dimensional (2-D) analysis of the same problem will be done for comparison with the 3-D results.

Technical Assistance on Special Repository Problems

Results from the RE/SPEC finite-element code series SPECTROM for comparison with those from the SAI explicit finite-difference code STEALTH were reported for a room scale benchmark problem.

Code Development and Verification

Progress was reported on updates made to SPECTROM 41 (TRANCO) to permit explicit definition of transient temperature boundary conditions. Development of SPECTROM 321, a 3-D thermoviscoelastic finite-element program which uses a "block solver", was completed. A draft report was submitted describing a comparison of numerical predictions and laboratory data for a bench scale experiment performed by the South Dakota School of Mines and Technology.

ACTIVITIES DURING THE REPORTING PERIOD

Room Scale Investigations

The Room Stability Working Group met to review the concerns related to room stability and how they relate to the overall plans for development of a repository in salt. A draft report reviews and evaluates the state of the art in room stability analysis and predictive capability and summarizes the recommendations of the working group regarding both limits on designs, geometries, operation, and retrieval scenarios as well as appropriate procedures to further room stability evaluations as an integral part of the overall program.

A draft report describes the 3-D thermal environments in a spent fuel repository in salt. For this problem geometry (20 percent extraction ratio) and thermal loading (14.8 W/m^2), the pillar temperatures reach a maximum of 75 C at 50 years. The maximum predicted salt temperature of 105 C is well below the lowest salt decrepitation temperature, and room temperatures throughout the assumed operational life of the repository (50 years) reach a maximum of 80 C.

The 3-D thermomechanical analysis of the above problem has been postponed. The analysis was to calculate the elastic stresses created by the excavation of the disposal room and connecting corridor into an initial lithostatic stress field. The numerical solution of the problem will require an excessive amount of in-core as well as peripheral storage because of the problem size. SPECTROM 321 is currently being optimized to minimize storage requirements and the corresponding cost of completing the analysis.

Repository Scale Investigations

The NWTS Working Group on Far-Field Performance Constraints developed performance constraints for repositories in basalt, granite, bedded and domal salt, and tuff. A draft report on the repository performance constraints in the far-field domain has been circulated to the Working Group for review.

Technical Assistance on Special Repository Problems

A coupled convective-conductive finite-element program has been modified to model the turbulent heat transfer process present in blast cooling. An axisymmetric room and pillar model similar to an infinite cylinder was chosen for an initial check run. The system was considered to be at an initial temperature of 120 C, with all boundaries considered adiabatic except for the pillar midplane and room inlet. The pillar midplane was maintained at a constant 120 C, and constant 26 C air was introduced at the room inlet at a velocity of 15 m/s. Predicted steady state room wall temperatures agree within 0.5 percent with a comparable analysis of the system using SPECTROM 41 with a specified convective boundary along the room wall. The room wall was considered hydraulically smooth. The coupled program has been modified to account for wall roughness effects, and blast cooling parametric studies have been started. The following parameters are being considered:

1. Cooling air velocity
2. Initial formation temperature at the start of blast cooling
3. Cooling air inlet temperature
4. Wall roughness
5. The thermal conductivity of salt
6. Cooling air relative humidity (dry versus saturated)
7. Room length.

The results of this study will provide a better understanding of the significance of the above parameters in the development of a blast cooling scenario if retrievability should become necessary.

Code Development and Verification

SPECTROM 321 was modified to accept 3-D skewed boundary conditions. This modification allows for reduction in size of some 3-D thermomechanical problems where lines of symmetry exist which are not normal to the global coordinate axes. Boundary conditions assigned to nodes may be prescribed displacement conditions which are normal to two axes but rotated through some angle with respect to the third. This feature could be used in the modeling of long tunnels, where every radial line is a line of symmetry.

A "block solver" was added to SPECTROM 342, a 3-D heat transfer finite-element computer code. Approximately 90 percent of the computer code storage required for the solution of 3-D problems with conventional finite-element programs is allocated to the in-core storage of the stiffness matrix. Addition of the block solver allows formation of the stiffness matrix and solution of the resulting simultaneous equations with only a portion or "block" of the stiffness matrix in core at any given time. This feature results in a significant increase in the size of problems which can be solved but is achieved at the expense of execution time and increased computer cost. The increase in cost has not been quantified at this time. This addition complements the increased problem-solving capabilities of SPECTROM 321 as previously reported.

Documentation of SPECTROM 41 was submitted to ONWI in draft form.

FUTURE ACTIVITIES

Room Scale Investigations

Work will start on the site characterization of the four candidate salt repositories: Richton, Vacherie, Permian Basin, and Paradox Basin. This will include identification of the parameters to be investigated, site-specific details, thermomechanical numerical simulations, and comparison of results obtained from the thermomechanical analyses of the four locations.

Repository Scale Investigations

The draft report on the repository performance constraints in the far-field domain will be revised to incorporate the comments of the Working Group and will be released for a comprehensive review by the nuclear waste disposal community.

Code Development and Verification

Implementation of different types of creep formulations which include steady state creep will be performed in parallel with the laboratory studies (see below) which are characterizing specimens from each of the four proposed repository sites in salt.

Documentation of SPECTROM 11, the finite-element thermoelastic-plastic computer program, is continuing.

TASK 2: LABORATORY STUDIES

(P. E. Senseny)

OBJECTIVE

The objective of this investigation is to study in the laboratory the constitutive behavior of geologic materials and to formulate constitutive laws that model the thermomechanical response of these materials under conditions expected in a nuclear waste repository.

This program provides constitutive laws that can be used by modelers to predict the stresses and deformations in a nuclear waste repository and to assess the stability of that repository.

PROGRESS REPORTED PREVIOUSLY

Creep data from 50-mm and 100-mm-diameter specimens of dome salt from Avery Island, Louisiana, showed that transient creep of the smaller specimen is more sensitive to stress, time, and temperature than is that of the large specimen.

Electronic modules were substituted for the mechanical differential pressure gages in the dilatometers in all six creep machines. The dilatometers now control confining pressure to approximately ±35 kPa and give clean lateral strain-versus-time records.

Initial results were presented showing the subgrain size at steady state of Avery Island dome salt as a function of axial stress difference. A least squares fit of the data yielded the equation:

$$D = 380\ \sigma^{-1.3} ,$$

where D is the subgrain size in microns and σ is axial stress difference in MPa.

ACTIVITIES DURING THE REPORTING PERIOD

The major part of the study of subgrain size at steady state as a function of axial stress difference is completed. Figure 1 presents subgrain size as a function of axial stress difference for dome salt from Avery Island. The equation fitted to this data is:

$$D = 190\ \sigma^{-1} ,$$

where D is subgrain size in microns and σ is the axial stress difference ($\sigma_1 - \sigma_3$) in MPa. The error bars in Figure 1 show the uncertainty in the results. The stress difference error bars represent the maximum positive and negative deviations

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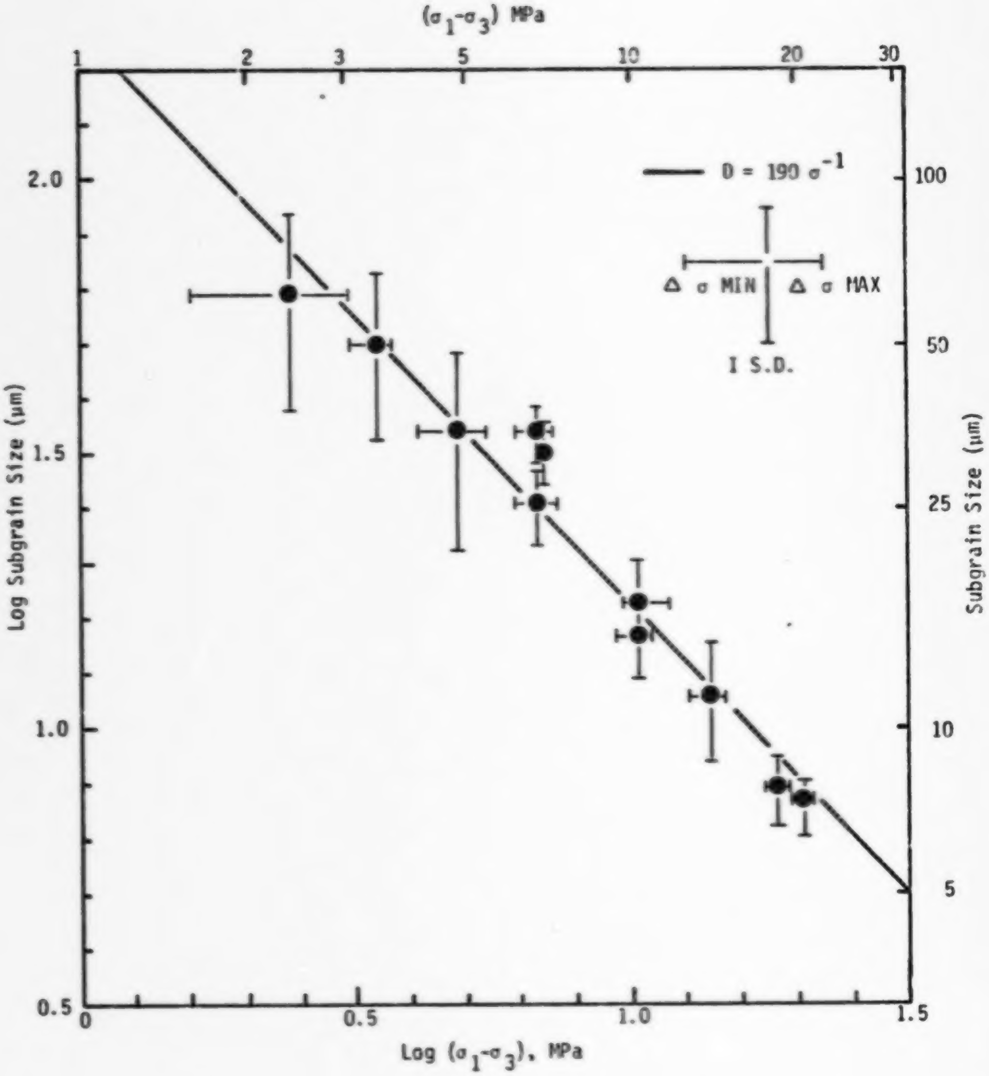

Figure 1. Subgrain Size at Steady State as a Function of Axial Stress Difference for Avery Island Dome Salt.

in axial stress difference from the mean axial stress difference during the experiment, whereas the subgrain size error bars represent one standard deviation above and below the mean subgrain size.

A matrix of tests has been prepared and is being performed on specimens of dome salt from Richton, Mississippi, and Vacherie, Louisiana, and on specimens of bedded salt from the Permian and Paradox Basins. The purpose of these tests is to provide quasi-static strength and creep deformation data that can be used to compare the suitability of these sites to host a nuclear waste repository. Of the planned creep tests, 90 percent are completed or are in progress, and about 15 percent of the quasi-static experiments are completed.

FUTURE ACTIVITIES

When the site characterization experiments are completed, experiments investigating the influence of stress history on creep will be started. Specimens that are tested in this program will also be studied microscopically to determine the influence of stress history on subgrain size.

TASK 3: AVERY ISLAND DATA ANALYSES

(R. A. Wagner)

OBJECTIVE

The objective of this task is to perform analytical and numerical evaluations of the field experiments performed at Avery Island, Louisiana. Present and future field experiments may be categorized as follows:

1. Heater
2. Brine migration
3. Accelerated borehole closure
4. Extended gas permeability
5. Fracture healing
6. Heated block
7. Rock mechanics measurement

The analyses or simulation of these experiments will help assess the in situ thermomechanical properties and evaluate the modeling techniques of situations related to the isolation of radioactive waste.

PROGRESS REPORTED PREVIOUSLY

An a priori numerical simulation of the accelerated borehole closure experiment made predictions that will be compared to actual field measurements upon completion of the experiment.

The numerical simulation of the Site A heater test at Avery Island was reported. Agreement between the predicted and field-measured temperatures was within 25 percent for the modeled region, with the closest agreement occurring along the midheight of the heater. Subsequent analyses are being performed to provide a comparison of predicted versus measured displacement and stresses.

ACTIVITIES DURING THE REPORTING PERIOD

Comparison and evaluation of the field-measured and numerically calculated temperatures, displacements, and stresses from the Site A heater test at Avery Island were completed. Figure 2 shows excellent agreement between the numerically calculated and field-measured vertical displacements along two of the four vertical extensometer locations. Results are presented at times of 100, 300, and 500 days for the two vertical extensometers which are located at a radial distance of 1.76 and 6.07 feet from the heater centerline. This direct comparison required an assumption that the field-measured displacement was identical to the numerical calculation at the lowest extensometer location (36 feet below the floor). This assumption is reasonable, since the movement at this location is nearly zero at the times considered and appreciable movement did not occur until after 100 days. The anomalous behavior along extensometer #3 suggests that rod slippage occurred between 300 and 500 days. Because of the inadequacy of the stressmeters, poor agreement was achieved between the field-measured and numerically calculated stresses.

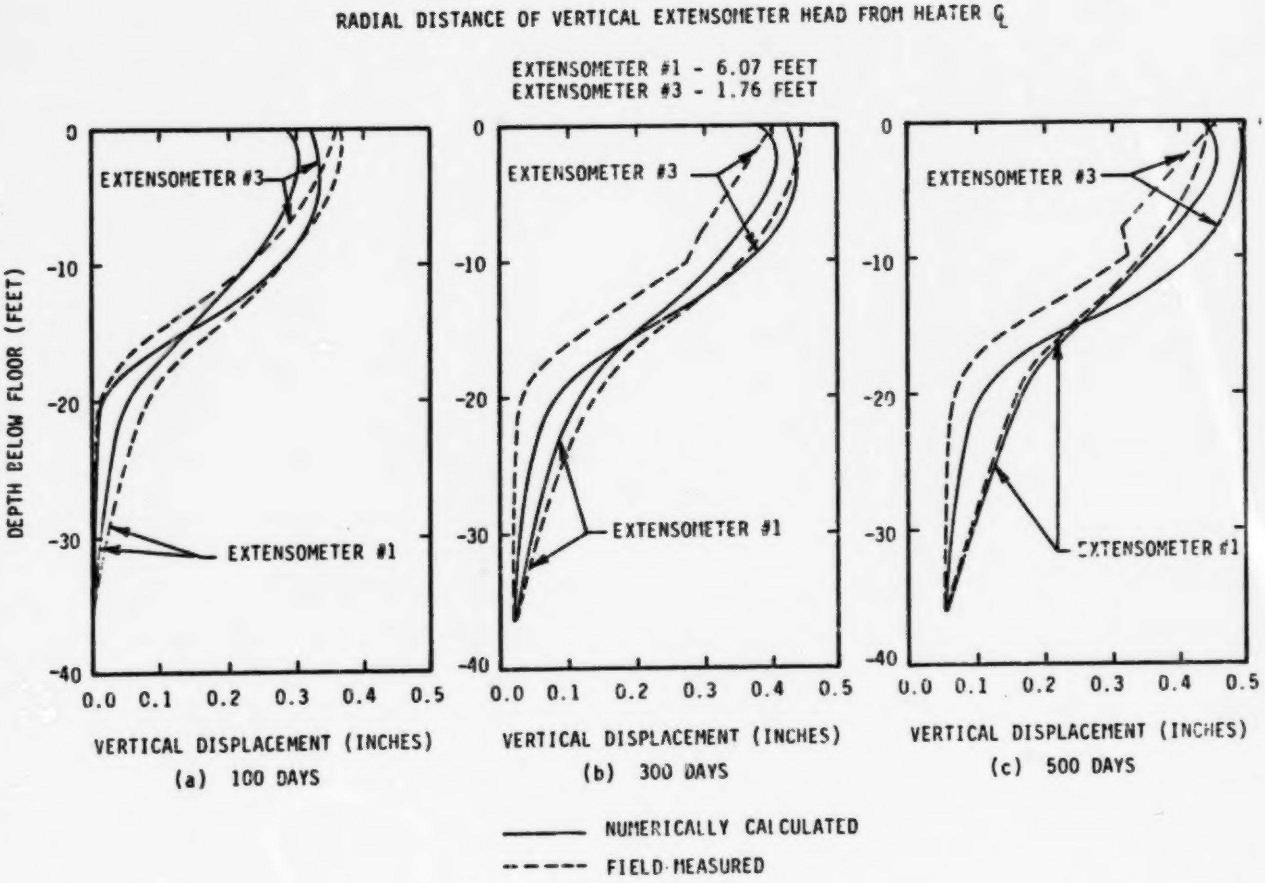

Figure 2. Comparison of Numerically Calculated and Field-Measured Vertical Displacements for the Site A Heater Test.

WBS 1.4.8

PROJECT: Convective Heat Transfer in Room and Pillar Geometries

PRINCIPAL INVESTIGATOR: Ohio State University (R. Christensen)

ONWI PROJECT MANAGER: G. E. Raines

OBJECTIVE

The objective is to determine the local and average convective heat transfer coefficients on the surfaces of a repository mine drift, and to measure the local temperature distribution in the drift. These heat transfer coefficients are needed to assess the ventilation and cooling requirements in the repository during waste canister emplacement and retrieval. Ventilation is required to ensure worker safety and may be required to limit the temperatures in both the repository and the waste package.

PROGRESS REPORTED PREVIOUSLY

A basic research effort was started in July 1979 to determine generalized heat transfer correlations for all interior surfaces of a room, using discrete thermal sources on the floor.

Typical room designs were determined, and the experimental design study developed into a model dynamically scaled to provide hydrodynamic and thermodynamic similarity. The dimensionless parameters that come into play are the Reynolds number, the Prandtl number, room aspect ratios (i.e., length to width, height to width), thermal loading schedule, total thermal load, and surface roughness. The laboratory model was two-dimensional and had a strip heater in the floor (to represent the heat generating waste) and insulated side walls.

A heat transfer correlation was obtained in the fully developed turbulent region of the channel over a range of Reynolds numbers from 1,600 to 88,700 for an aspect ratio of 1.5. This correlation has been found to agree favorably with correlations for mixed convection over the entire range of Reynolds numbers.

ACTIVITIES DURING THE REPORTING PERIOD

During the quarter significant progress has been made in obtaining a correlation for fully developed Nusselt numbers in a rectangular duct with aspect ratio 1.0. Reynolds numbers ranged from 98,300 to 32,000. In addition, three regions have been identified in the rectangular duct: laminar, transition, and fully developed turbulent flow. The thermal and hydrodynamic entry length has been determined for the above ranges of Reynolds numbers.

Forced convection appears to exist in the rectangular channel with an aspect ratio of 1.0 for values of Reynolds numbers ranging from 98,300 to 32,000. Reynolds numbers were set at 98,300, 83,000, 73,000, 59,000, and 32,000. At each value, data were taken for the entire heated length of the tunnel at power levels of 3, 4, 5, and 6 W/heater. Local Grashof and Nusselt numbers were calculated for each run; the Nusselt numbers are plotted versus nondimensional heated length in Figure 1. This figure illustrates the three regions of interest. Table 1 gives the approximate length of each region.

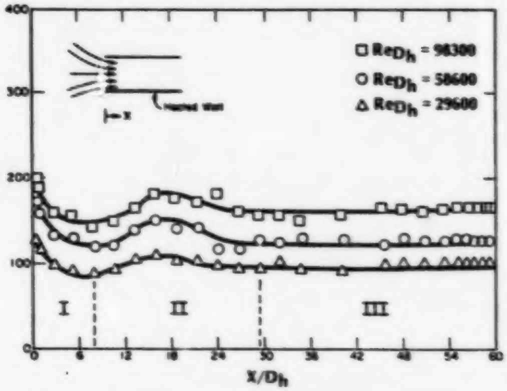

Figure 1. Variation of Local Nusselt Number (I - Laminar, II - Transition, III - Fully Developed Flow Regime).

Table 1. Length of Flow Regions in the Rectangular Duct.

Region	Length (# of Hydraulic Diameters)
I. Laminar	7
II. Transition	23
III. Fully Developed	30

In the Laminar Region (I), large velocity and temperature gradient have been found at the wall which result in high friction losses and high-heat transfer. As the boundary thickens, heat transfer rate decreases.

In the Transition Region (II), velocity and temperature distribution adjust to a developed form. It is suggested that the initial increase in Nusselt number in the region is due to the following causes:

1. Unstable Tollmien-Schlichting waves
2. Three-dimensional waves and vortex formation
3. Bursting of vortices (Schlichting, 1979).

The subsequent decrease in Nusselt number ($18 < X/D_h < 30$) is due to creation of turbulence.

The data from Region III have been plotted versus Grashof numbers in Figure 2. For an aspect ratio of 1.0, it is found that Nu_∞ is independent of Grashof number. For example, at Re = 59,000, Grashof number varied from 5.5×10^6 to 2.2×10^7, but there is a negligible change in Nu_∞. This is an indication of forced convection. In addition, Figure 2 shows parallel lines at constant Reyonlds number. Therefore, they have been correlated together by linear regression techniques in the form of

$$Nu_\infty = 2.13\ Re_{D_h}^{0.374}.$$

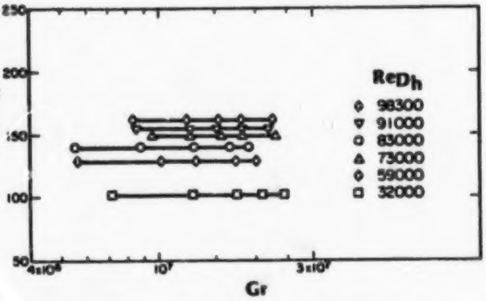

Figure 2. Nu_∞ vs. Grashof Number.

This correlation, obtained for fully developed heat transfer in a rectangular duct, and a correlation obtained for fully developed heat transfer in a smooth pipe reported by Sparrow (1957) ($Nu_\infty = 0.0245\ Re^{0.77}$) are plotted in Figure 3. For Reynolds numbers ranging from 7.8×10^4 to 1×10^5, Nu_∞ for smooth pipe is 0 to 6 percent higher than that of rectangular duct. For Reynolds numbers ranging from 6.2×10^4 to 7.8×10^4, Nu_∞ for rectangular ducts is 0 to 9 percent higher than that of smooth pipe. At Reynolds number = 3.2×10^4, the Nusselt number for the duct is 42 percent higher than that of a smooth pipe.

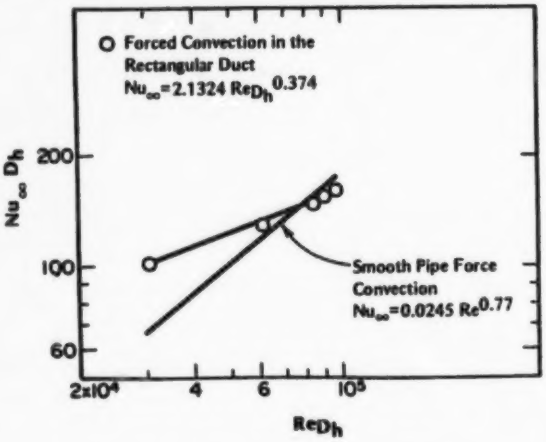

Figure 3. Nu_∞ vs. Reynolds Number.

In the Fully Developed Region (III), since the temperature and velocity profiles are fully developed, the Nusselt numbers are asymptotic. It is of interest to point out that for Reynolds numbers ranging from 98,300 to 32,000, the thermal entry region length appears to be constant.

Thermal entrance length will be defined here as that value of X/D_h at which Nusselt number approaches within 5 percent of the fully developed value, which for the present experiment is about 30 hydraulic diameters. This is important for repository design. If a repository room is much greater than 30 hydraulic diameters in length, then the asymptotic Nusselt number will give fairly accurate heat transfer results. On the other hand, if the repository room is on the order of 30 hydraulic diameters, then heat transfer correlations for the entrance region must be used. Thus strong incentive exists for evaluating the Nusselt numbers in the entrance region.

FUTURE ACTIVITIES

Since the boundary layer development, and hence the thermal entrance region, is strongly influenced by characteristics of the duct's entrance and free steam velocity, two additional duct entrances other than that currently being used (a sharp-edged entrance) will be investigated. These will include a T-shaped entrance and an elbow entrance.

REFERENCES

Schlichting, H., 1979. Boundary-Layer Theory, 7th edn., McGraw-Hill Book Company, New York, NY, p. 483.

Sparrow, E. M., 1957. "Turbulent Heat Transfer in the Thermal Entrance Region of the Pipe with Uniform Heat Flux", Applied Scientific Research, Vol. A7, p. 32.

WBS 1.4.8

PROJECT: Convective Heat Transfer Within Spent Fuel Canisters

PRINCIPAL INVESTIGATOR: University of Delaware (F. A. Kulacki)

ONWI PROJECT MANAGER: G. E. Raines

OBJECTIVE

The objective is to provide basic engineering data and correlations for heat transfer from rod bundles typical of spent fuel subassemblies in enclosed canisters. The heat transfer coefficients are to be obtained from laboratory measurements and will be corrected for the effects of thermal radiation. Bundles containing a 5 x 5 rod array and smaller arrays will be considered to provide a basis for a generalized heat transfer correlation. Constant temperature and mixed-type boundary conditions on the canister wall will be used in separate phases of the study.

PROGRESS REPORTED PREVIOUSLY

Previous work on this task included the design, construction, and testing of a vertical circular cylinder (referred to as the "small apparatus") for studies of free convection from a single rod (annulus case) and rod bundles containing four, five, and nine rods. In all cases, the rods are electrically heated with specific power generation scaled to that expected in an actual fuel rod bundle [PWR fuel with 33,000 megawatt day (MWD) burnup, 5 years old]. At the end of FY 81, heat transfer results for the annulus case were obtained for the laminar (conduction), transition, and turbulent regimes of free convection.

Two correlations were developed for average heat transfer coefficients, or Nusselt numbers, as a function of Rayleigh number based on gap width and average temperature difference between the walls of the annulus. For the laminar (sometimes referred to as the conduction regime), the correlation is

$$Nu = 1.406\ Ra^{0.077}$$

for $10^3 \le Ra \le 6 \times 10^3$. Heat transfer data for the transition and boundary layer regimes could be combined into one correlation since the measurements did not permit a sharp distinction to be made between the two regimes of convection. The correlation is

$$Nu = 0.163\ Ra^{0.322}$$

for $6 \times 10^3 \le Ra \le 2.4 \times 10^6$.

The preliminary results of experiments with the 3 x 3 square array rod bundle have been satisfactory.

ACTIVITIES DURING THE REPORTING PERIOD

Preliminary experiments with the 3 x 3 square array rod bundle continued during the reporting period. Also, the construction and instrumentation of the large-scale (5 x 5 square array rod bundle) experiment were completed.

Another apparatus has been designed and fabricated to be used to study the dependence of heat transfer coefficients on the aspect and radius ratios. It will cover the ranges of aspect ratios and radius ratios of interest when the spent fuel assembly canister system is treated as a thermally equivalent rod enclosed in a cylinder. The data obtained from this apparatus coupled with those from the earlier apparatus are expected to give detailed correlations of Nusselt number versus Rayleigh number, aspect ratio, and radius ratio, and thus will be more helpful in predicting heat transfer coefficients in spent fuel assemblies in enclosed canisters.

The apparatus consists of five major components: the top plate, bottom plate, cylinder, heat rod, and water jacket.

Figure 1 shows the arrangement of the apparatus with the top plate for one of the rods in place. The vacuum check and preliminary runs on this apparatus have been satisfactory. Data will be collected using this apparatus in the upcoming quarters.

FUTURE ACTIVITIES

The large and small apparatus plus ancillary equipment will be set up so that experiments can begin. The experiments with the newly built experimental apparatus will continue.

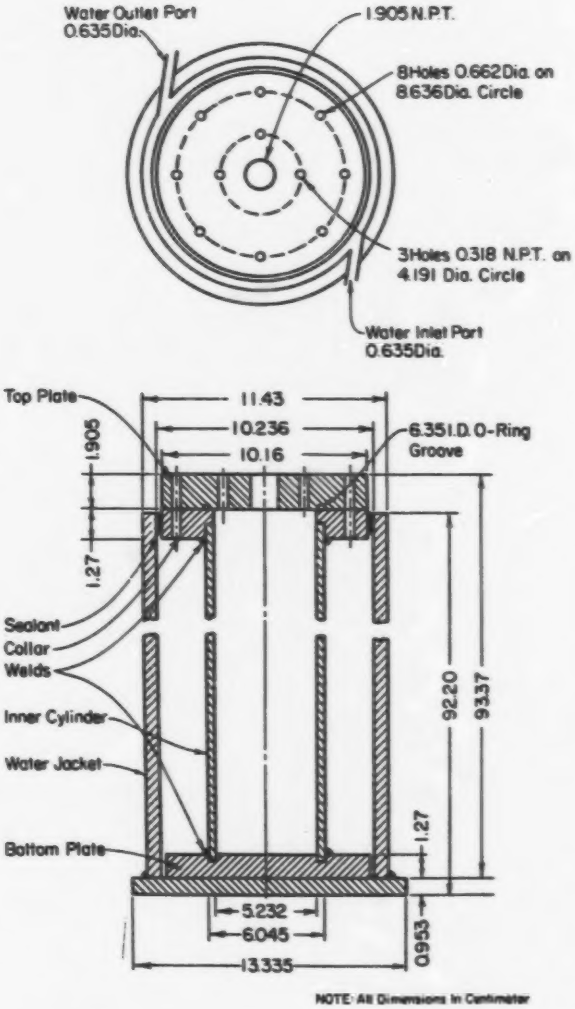
Water Outlet Port 0.635Dia.
1.905 N.P.T.
8Holes 0.662Dia. on 8.636Dia. Circle
3Holes 0.318 N.P.T. on 4.191 Dia. Circle
Water Inlet Port 0.635Dia.
Top Plate
11.43
10.236
10.16
6.35 I.D. O-Ring Groove
1.905
1.27
Sealant
Collar
Welds
Inner Cylinder
Water Jacket
Bottom Plate
9.220
9.337
1.27
5.232
6.045
13.335
0.953
NOTE: All Dimensions In Centimeter

Figure 1. Detail of the Experimental Apparatus.

WBS 1.4.8

PROJECT: The Effects of Far-Field Inhomogeneities on Surface Temperature and Heat Transfer From a Repository

PRINCIPAL INVESTIGATOR: Ohio State University (A. T. Conlisk)

ONWI PROJECT MANAGER: G. E. Raines

OBJECTIVE

The objective is to calculate approximate temperature profiles within geologic media that are subject to a spatially finite, time-dependent heat source. Property variations are to be incorporated into the model, and various source (repository) geometries will be considered. The corresponding linear (constant property) solutions will be compared with the nonlinear (variable property) solutions. Where possible, analytical closed-form solutions to the fundamental partial differential equation will be given; in the nonlinear problem, such a solution does not appear possible, and the temperature distribution within the geologic medium will be computed numerically.

PROGRESS REPORTED PREVIOUSLY

The heat balance integral method has yielded the time history of the temperature distribution within the geologic medium with a minimum of complexity and numerical computation. However, the studies do not appear to take into account the nonlinear nature of the problem, although mechanisms for generalizing the method to this case appear to exist.

The effect of a temperature-dependent conductivity upon the heat transfer from a nuclear waste repository is being evaluated. As an alternative to the heat balance integral method, the problem was formulated as a nonlinear partial differential equation with appropriate boundary conditions. Results for a single-slab, one-dimensional model problem were calculated, with solutions obtained for both the linear (constant conductivity) and nonlinear (varying conductivity) problems and a comparison made of the calculations for granite in each case. The results tended to confirm that varying conductivity can have a significant effect upon the temperature distribution within the repository.

Measurements of the temperature distribution within a model repository were begun. Due to problems associated with the time constant of the system as well as its lack of versatility, this model will not be employed in the future. In its place a new, more versatile system has been designed. To compare results with the experimental measurements, analytical work was begun for a two-layer, one-dimensional model of a repository.

ACTIVITIES DURING THE REPORTING PERIOD

Introduction

Progress has been made in the experimental and analytical areas. Experimentally, a new model repository was designed and constructed. The previous model was limited by the fact that only one repository configuration could be tested. The new design permits more versatile geometrical configurations, and the dimensional properties of the system have been improved.

Analytically, the two-layer, one-dimensional linear model of the repository has been analyzed. An important parameter of the present model is the fraction of heat passing above (or below) the repository. This fraction is parametrically dependent only on the time constants of the two layers, given a specific spent fuel source term. This result is important in the design of the repository, since the amount of heat which eventually reaches the surface of the earth is directly dependent on this fraction.

In addition, a two-dimensional model with varying stratigraphy is presently being coded for the computer; the analytical results will be compared with those of experiments conducted with the new model repository.

Experimental Apparatus Design

The basic criterion for the design of the new repository was versatility. Thus, multiple geometries can be tested without constructing a new model for each geometrical configuration. Therefore, a single gypsum plaster block was poured to act as a semi-infinite body so that different materials can be laminated and placed upon the block to simulate the desired test case. A locking device was also designed to ensure good contact between the laminate and the plaster block. A 6 x 12-inch heating strip simulates the nuclear waste repository. With this new model, assembly time for a test should be less than one hour. Furthermore, tests with different geometries can be run within 24 hours of each other. A sketch of the new model appears in Figure 1.

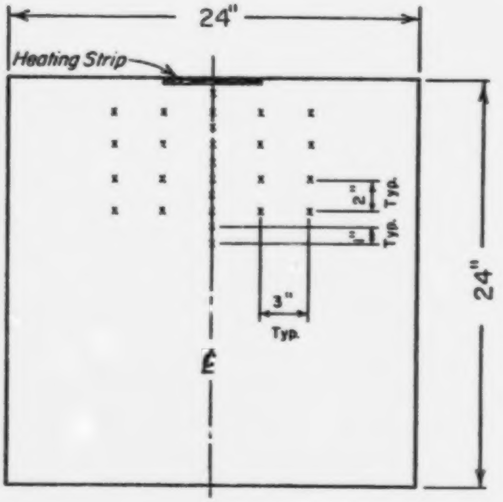

Figure 1. Thermocouple Positions in the Lower Portion of the Repository Model.

Analytical Activity

A linearized multilayer, one-dimensional model of heat conduction from a repository has been analyzed. The geometry of the model is depicted in Figure 2. Analytical closed-form solutions can be obtained for constant conductivities in each of the layers. In this report solutions for the fraction of heat passing into the upper layer ($1-\gamma(t)$ in Figure 2) will be presented for two different heat source functions.

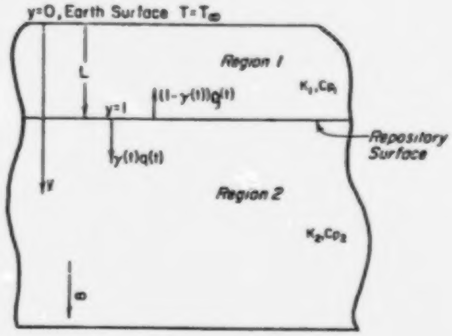

Figure 2. Stratigraphy for the Two-Layer Model.

In general, the temperature distributions in each of the layers must be solved simultaneously; the solutions are then matched together at the source plane by requiring continuity of temperature. This matching procedure leads to an expression for $\gamma(t)$ according to

$$\gamma(t)q(t) =$$

$$L^{-1}\left\{\frac{\beta \sinh \sqrt{\tau_1 s}}{\cosh \sqrt{\tau_1 s} + \beta \sinh \sqrt{\tau_1 s}} \int_0^\infty e^{-st} q(t)\,dt\right\} . \quad (1)$$

In Equation (1),

$$\beta = \sqrt{\frac{k_2 \rho_2 Cp_2}{k_1 \rho_1 Cp_1}} ,$$

and $\tau_1 = \rho_1 Cp_1 L^2/k_1$; here Cp, ρ, and k denote the specific heat at constant pressure, density, and thermal conductivity of the indicated layer. Also in (1), q(t) is the heat generation function and L^{-1} denotes the inverse Laplace transform. For $\beta \neq 1$ the inversion of (1) appears to be difficult and further analysis of this problem is proceeding; however for $\beta = 1$, Equation (1) can be inverted readily for a wide variety of heat source functions q(t). Two such functions are discussed below.

For $\beta = 1$ and uniform heat generation where $q = q_o$ = constant, it can easily be shown that $\gamma(t) = 1/2q_o \text{ erf } \sqrt{\tau_1/t}$. Thus $\gamma(t)$ is parametrically dependent only on the time constant of the upper layer of Figure 2. As $t \to \infty$, all the heat is expected to pass into the upper layer. This result is important from the design point of view, since a material with a small time constant τ_1 would tend to pass heat more readily than a material with large time constant. This principle is illustrated in Figure 3 where τ_1 = 11,511 years for salt and 27,905 years for granite. Consequently, $1-\gamma$ salt → 1 faster than $1-\gamma$ granite.

Solutions for $\gamma(t)$ were also computed for PWR fuel in which $q(t) = \sum_{i=1}^{n} C_i e^{-\lambda_i t}$, where C_i and λ_i are constants. Inversion of the corresponding Laplace transform given in equation (1) leads to:

$$\gamma(t)\, q(t) = 1/2\, q(t) - \frac{\tau_1}{\pi} \sum_{i=1}^{n} \int_0^t \frac{C_i e^{-\{\lambda_i(t-u) + \tau_1/u\}}}{u^{3/2}}\, du\,. \tag{2}$$

The integral in (2) was evaluated numerically using Simpson's rule with self-adjusting error control; the maximum local relative error was less than 10^{-4}. The results of numerically integrating (2) are also presented in Figure 3 and are depicted by the dashed lines in this figure.

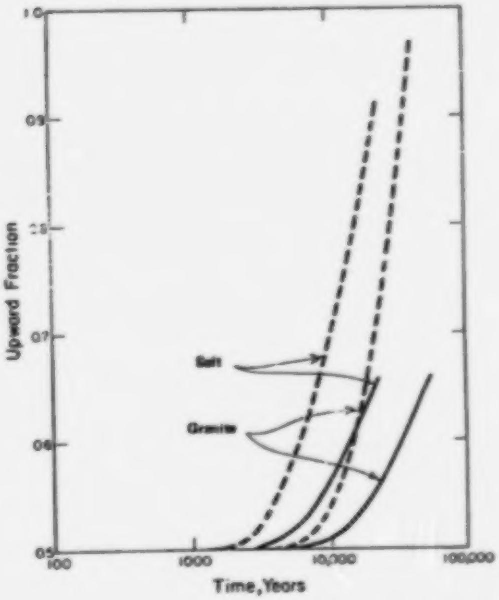

Figure 3. Fraction of Heat Which Passes into the Upper Layer of Figure 2. (Calculations are for salt and granite. The solid lines denote constant heat flux, while the dashed lines denote PWR fuel.)

In addition, two-dimensional analysis has begun for stratigraphies similar to those mentioned previously. The doubly infinite horizontal domain can be compressed into the region [0,2] by the transformation $\zeta = 1-2/\pi \tan^{-1}x$. Computationally, this transformation has the effect of reducing the large number of mesh points required by the doubly infinite region.

FUTURE ACTIVITIES

During the next quarter, experimental measurements will begin for different repository stratigraphies. At least one geometry will include a finite foreign inclusion. Work will be completed on the one-dimensional, two-layer model (both linear and nonlinear problems). In addition, the effect of overburden on the heat transfer will be investigated.

The two-dimensional model code is expected to be completed for one of the stratigraphies, and comparisons with experimental data will be made.

The constant temperature boundary condition which is imposed at the earth's surface in the present work will be reexamined. Such analysis is expected to lead to design criteria for the repository based on small but nonzero variations of the surface temperature.

WBS 1.4.8

PROJECT: Development of ROCMAS (Thermo-Mechanical-Hydrological) Code

PRINCIPAL INVESTIGATOR: Lawrence Berkeley Laboratory (C. F. Tsang and J.S.Y. Wang)

ONWI PROJECT MANAGER: M. R. Wigley

OBJECTIVE

The objectives of this project are to develop a model simulating thermohydromechanical flow in fractured rock masses and to monitor the state of the art in modeling of fractured systems. This modeling capability is needed to predict the effects of waste heat and to assess the movements of ground water and possible radionuclides between the repository and the biosphere.

PROGRESS REPORTED PREVIOUSLY

The ROCMAS code, for thermally induced hydromechanical calculations, was developed, validated, and implemented. In this version, the heat conduction equation is solved and the temperature distribution is used directly in the coupled hydromechanical analysis. The capability for calculating the thermally induced fluid flow velocity was tested against the analytic solutions for the movement of a thermal sharp front.

Current capabilities for modeling fractured rock masses have been reviewed. This review is the generalization of the FY 80 assessment of the state of the art in modeling.

ACTIVITIES DURING THE REPORTING PERIOD

Both the application and the development of the thermohydromechanical fractured rock code ROCMAS were emphasized this quarter. Generic applications were made for thermomechanical deformations and for hydromechanical processes in fractured rocks. Also, the paper on the status of modeling was reviewed.

The thermomechanical deformation of a fractured rock column has been modeled. The column contains one, two, or five fractures. After the temperature at one end of the column is increased instantaneously, the heat conduction and rock displacement within the fracture column are calculated. At an early time, the closure of the fracture absorbs the thermal expansion of the rock blocks. After all of the fractures are closed, the rock mass behaves as a continuum. The transition between discrete and continuous behavior is sharp, with a kink structure in the displacement-time plot. These modeling results indicate that displacement measurements may yield information about fracture properties such as aperture, spacing, stiffness, etc. Additional generic studies should improve the basic understanding of thermomechanical processes and assist the interpretation of field data.

The hydromechanical coupling of an injection well test for a fractured medium has been studied. As high fluid pressure propagates into a fracture, the fracture opens and the flow rate increases. Hydromechanical coupling is most evident when the high pressure is distributed over the whole length of the fracture. An anomalous flow rate increase occurs in the late transient before the steady state condition is established. This may be due to the special boundary conditions selected. A draft on the numerical simulation of fluid injection into deformable fractures has been prepared.

The modeling results of ROCMAS, in the cases studied, clearly demonstrate the importance of coupling among thermohydromechanical processes and point out the inadequacy of continuum models for fractured rock masses in certain classes of problems.

The code debugging of the improved version for thermally induced hydromechanical simulations has been completed. This version has the capability of calculating the thermal field both numerically for complex geometry and analytically for simple systems.

A paper on the status of modeling flow and transport in fractured rock masses for radioactive waste isolation discusses fluid flow, rock deformation, heat transfer, and solute transport in fractured rock formations.

FUTURE ACTIVITIES

The development, validation, and application of the thermohydromechanical fractured rock code ROCMAS will continue. Emphasis will be shifted to verifying and applying different versions of the code. Additional generic studies will be made to improve the understanding of coupled processes and assist in the interpretation of field data.

WBS 1.4.8

PROJECT: Boundary Element Model Development--Repository Design Studies

PRINCIPAL INVESTIGATOR: University of Minnesota (B.H.G. Brady)

ONWI PROJECT MANAGER: M. R. Wigley

OBJECTIVE

There are two major objectives of this work. The first is to develop and apply boundary-element computer models for thermomechanical analyses of repositories in bedded salt. The second is to develop constitutive models for the inelastic, time-dependent behavior of salt through laboratory investigation of its response under varying loading conditions.

PROGRESS REPORTED PREVIOUSLY

Initiated in June 1976, this program has resulted in several boundary-element computer codes capable of analyzing a range of problems posed in the design of a waste repository in salt. These codes are mainly intended for studies of the far-field response of a rock mass to emplaced heat sources. In March 1980, investigations related to constitutive law development for salt were included in the program. This has involved the construction of an extensive laboratory facility, with close control of thermal environmental conditions, a bank of sample monitoring systems, and an advanced system for collecting and recording experimental data.

The last topics considered were as follows:

1. In the design studies, the results of a series of sensitivity analyses using the SALTY code were presented, and work on the REPOS code was discussed.
2. In code development, some aspects of the development of hybrid finite-element/boundary-element codes were described.
3. In the laboratory investigations, the status of development of the laboratory facility was described. A number of problems in the performance of components were defined.

ACTIVITIES DURING THE REPORTING PERIOD

Laboratory Investigations

Assembly of the laboratory facility has been completed, and calibration activities are under way. Major efforts are being directed towards code development of the data-handling system. A significant portion of the code work is completed, and program verification is in progress.

The process obtaining a hard copy of experimental data is currently under investigation. Recently, low-cost digital X-Y plotters and high-quality graphic printers have become available.

Code Development and Verification

Work under this task is proceeding in three areas:

Interactive Computer Graphics. The general strategy to be pursued in development of interactive boundary-element codes was defined. Development of codes for interactive computing began. To date, routines have been completed for input of material properties and data storage, and for graphical input of problem geometry.

Finite-Element/Boundary-Element Hybrid Code. The code described previously was modified to handle steps in an excavation sequence, or increments of loading of the system. A topical report on the method of analysis is being prepared.

Isoparametric quadratic elements, to describe surfaces in the infinite elastic domain, were successfully introduced in the boundary-element code. Introduction of compatible isoparametric finite elements is continuing.

As a prelude to introducing creep and other complex constitutive behavior in the finite-element domain, an extensive study was undertaken of the literature related to modeling creep in salt and other materials. Considerable diversity was observed in both the formulation of creep laws and the way in which these laws are implemented in a computer code.

Boundary-Element Codes for Two-Dimensional Transient Thermoelasticity. In an effort to achieve better computational efficiency, an iterative solution procedure was adopted. It was found that an indirect formulation for the algorithm required determination of problem variables in the exterior region. Work was therefore undertaken to establish a direct boundary-element formulation, which avoids the noted deficiency.

The new formulation has been found to be more economical than the indirect formulation and, for Dirichlet-type problems, achieves better accuracy. However, unstable performance of the algorithm was found for uses in which the time-step employed in the computational cycle was too small. Further work is planned to identify the causes of this problem.

Generic Design Studies

Work was completed on the REPOS code. This is a routine which models the three-dimensional thermomechanical response of an elastic rock mass containing a salt horizon in which are emplaced heat sources. Some modifications were made to the code segment which models creep history of the salt layer. Documentation of the code has been completed.

FUTURE ACTIVITIES

The performance of the code for the direct boundary-element formulation for two-dimensional transient thermoelastic analysis is to be assessed to define conditions causing instability. The finite-element/boundary-element hybrid code for isothermal, plane strain analysis will be upgraded to include complete plane strain.

WBS 1.4.8

PROJECT: ONWI Support Program: Effects of Water in Salt Repositories

PRINCIPAL INVESTIGATOR: Oak Ridge National Laboratory (C. F. Baes, Jr.)

ONWI PROJECT MANAGER: G. E. Raines

OBJECTIVE

The objective of this program is to predict from experimental and modeling studies those consequences of the presence or the ingress of water to a salt repository that might compromise the integrity of the repository.

PROGRESS REPORTED PREVIOUSLY

The principal effort has been the study of the kinetics of salt consolidation in the presence of brine. The results of extensive measurements as a function of particle size, particle size distribution, applied stress, fluid composition, column dimensions, and temperature have been fitted with a simple expression based on the kinetics of sintering. In general, extrapolation of the results to repository conditions confirms the self-sealing properties of bedded salt.

In progress is a study of the loss of permeability to brine at the interface between two salt crystals as a function of the initial condition of the surfaces and the uniaxial stress applied normal to the interface. In addition, brine migration and permeability are being measured in larger (10 cm diam.) halite cores as a function of the applied temperature gradient and uniaxial stress.

ACTIVITIES DURING THE REPORTING PERIOD

A consolidated (10 cm diam.) salt cylinder prepared from 0.025 to 0.042-cm salt crystals in brine was subjected to an axial temperature gradient of 2 C/cm in the range 25 to 45 C and a pressure of 138 bars. Parallel helium gas streams traversing the cold and hot surfaces showed contrasting rates of moisture removal. Collection of moisture from the upper (cooler) surface was linear with time (1.6 mg/hr), whereas the collection rate from the lower (warmer) surface was logarithmic with time and on an average was greater (9.4 mg/hr). Analysis of the salt cylinder after the experiment indicated that water removal was complete. In a second (otherwise similar) run at 75 to 95 C and an axial pressure of 155 bars, the consolidation kinetics were found to agree quite well with a prediction from the previously developed expression for consolidation in smaller columns ($\leq$ 2.5 cm diam.). Moisture removal rates were again slower from the upper (cooler) surface than from the lower (warmer) surface (averaging 2.0 and 76 mg/hr, respectively) after 196 hours. Following the cessation of consolidation, the amount of water vapor removed by helium flow corresponded to the volume of brine required to occupy the remaining void fraction (0.015). Helium permeability was measured at 10^{-16} cm^2 (10^{-2} microdarcy), while brine permeability was unexpectedly higher, 10^{-14} cm^2 (1 microdarcy).

Measurements of the permeability (Pm) to brine of an annular interface between two salt crystals at 20 C have been completed this period. Uniaxial crystal loadings from 17.5 to 140 bars were applied. The decrease of permeability with time (t) for each applied stress was fitted by a general least-squares computer program (ORGLS) to the empirical log Pm versus log t relation previously presented. Modifications to the experimental equipment now permit measurements to be performed over the temperature range from 20 to 95 C. Improvements in the apparatus include better temperature control (to ± 0.01 C) and reduction of vibration to improve the performance of the recording balance which is now accurate to 1 mg. A graphics program, DISPLA, was adapted to generate rapid graphic displays of stored data with a considerable reduction in labor. Measurements at 50 C are under way, with the data being collected by computerized logging equipment.

A model is being developed which represents the grain boundary as a two-dimensional region containing a mixture of salt crystals and void space. The crystals are assumed to consolidate with the previously employed sintering model, but be adapted to two dimensions. The adjustable parameters include the initial size of the "crystals" (corresponding to the irregularities that separate the large crystals forming the boundary), the initial void fraction of the interface, and two rate constants which define the consolidation kinetics. Permeability versus time curves generated with this model are of the appropriate form and suggest that this model will be quite useful as an improved representation of the data being collected.

FUTURE ACTIVITIES

The following activities are planned:

1. Measurement of grain-boundary permeability at elevated temperatures will proceed.
2. The model representing salt grain boundaries will be validated against the data obtained.
3. In the sutdy of brine migration and permeability of salt cores, the conditions of applied stress, temperature gradient, particle size, brine composition, and impurity content will be varied systematically to provide a data base for testing the models of salt consolidation and grain boundary permeability.
4. Efforts to measure the migration of brine through various salt-brine configurations under stress and in a temperature gradient will continue.

WBS 1.4.8

PROJECT: Analysis of Thermal/Mechanical/ Hydrological Response of Rock

PRINCIPAL INVESTIGATOR: Science Applications, Inc. (R. Hofmann)

ONWI PROJECT MANAGER: M. R. Wigley

OBJECTIVE

The objectives of this study are: (1) to further develop and verify special-purpose versions of the computer code system STEALTH, which will be used to aid in the design and licensing of a nuclear waste repository; (2) to document this development, verification, and use of the STEALTH computer code system as it applies to geologic isolation of nuclear wastes; and (3) to perform generic design studies that will form the design and licensing data base for site-specific analyses.

PROGRESS REPORTED PREVIOUSLY

The project was started 1 October, 1980, with five initial tasks:

1. Gather a set of meaningful analytic comparison tests and perform four cases using STEALTH
2. Perform one code-to-code comparison test comparing a STEALTH code to a SPECTROM code
3. Perform one bench-scale comparison test using data generated by the South Dakota School of Mines (SDSM)
4. Complete the Project Salt Vault (PSV) and Stripa simulations using the best available constitutive data
5. Establish a quality assurance basis for ONWI's use of the STEALTH code system.

The main thrust of the work in the first quarter of FY 81 was to establish the quality assurance basis for the various simulations that will be performed. The steps taken to reach this goal include (1) rerunning previous simulations on a PRIME 750 computer to verify hardware independence of the STEALTH codes, (2) writing a Quality Assurance Plan (QAP) which will govern ONWI-specific STEALTH developments, and (3) creating a base set of STEALTH files for use in future calculations.

So far, the steps to achieve these goals have been accomplished with minimal difficulty. Old PSV and Stripa runs have been successfully rerun, using current STEALTH files, version 3-21. Also, ONWI-specific STEALTH updates have been converted to the ATLAS program maintenance system.

An asymmetric simulation of PSV and axisymmetric simulations of Stripa using the best available salt and granite constitutive data, respectively, were completed. The results of these calculations were reduced and reviewed in preparation for writing topical reports.

Work also began on building a library of analytic test cases. The list of candidate problems is being compiled so that four problems can be chosen for computation by STEALTH. It was determined that the SDSM uniaxial experiment was inappropriate for use as a laboratory-scale simulation test.

ACTIVITIES DURING THE REPORTING PERIOD

Current activities have included extensive data reduction of the PSV and Stripa calculational data, additional two-dimensional plane strain Stripa simulations, writing topical reports on the analytic comparison tests and STEALTH cases and for the PSV and Stripa simulations, scoping the repository-scale code-to-code comparison calculation, and defining the SDSM replacement simulation.

FUTURE ACTIVITIES

The five initial tasks are scheduled for completion through the following activities:

1. Submission of PSV and Stripa topical reports
2. Completion of the STEALTH-SPECTROM-SALTY repository-scale, code-to-code comparison, and topical report
3. Completion of the SDSM replacement task with no report
4. Completion of topical report on analytic test cases.

WBS 1.4.8

PROJECT: Analysis of Flow Through Fractured Crystalline Rock

PRINCIPAL INVESTIGATOR: University of Waterloo (J. E. Gale)

ONWI PROJECT MANAGER: M. R. Wigley

OBJECTIVE

This project has two tasks: the Stripa fracture hydrology data analysis and the permeability size-effect study. The objectives of the Stripa analysis are (1) to characterize the rock mass fracture parameters by (a) using standard rock engineering approaches to characterize the rock mass and (b) completing a thorough statistical analysis of the fracture data, (2) to undertake a thorough assessment of the physical hydrogeologic characteristics of the Stripa site using the available borehole packer test data, and (3) to analyze an existing series of laboratory and field pressure pulse tests.

The objective of the permeability study is to determine, from laboratory studies, an empirical size-effect relationship between fracture permeability and the size of the fracture plane being tested in an attempt to determine the relationship between laboratory and field results. This project will (1) ensure continuity between the field data collection and the interpretation of the fracture hydrology data from Stripa, and (2) result in a well-documented data base being subjected to a thorough, systematic analysis. The two tasks combined will assist ONWI's NWTS program of fracture hydrology investigations by contributing to the procedures and methodologies required to evaluate flow through fractured rock masses.

PROGRESS REPORTED PREVIOUSLY

This project started on 13 March, 1981. The main thrust of activities in analyzing the Stripa fracture hydrology data so far was directed toward analyzing the basic fracture data. This consisted primarily of calculating the true strikes and dips of the fractures from the relative orientation measurements on the core and orientation and cluster analysis. This is an essential first step in a proper integration of the fracture and hydrologic data from the Stripa site.

In the laboratory study on the effects of sample size on fracture permeability, a full set of core samples (ranging from 10 to 30 cm in diameter) and a rock block of Charcoal Black Granite (from which an induced fracture will be cored) were collected. Each core sample contains a single natural fracture oriented normally to the core axis. Each core will be cut to a length-diameter ratio of approximately 2:1 and permeability tested under radial flow conditions over a range of 0 to 30 MPa of uniaxial compressive stress. A topical report describing the sample collection and engineering test plan has been drafted.

ACTIVITIES DURING THE REPORTING PERIOD

Stripa Fracture Hydrology Data Analysis

The main objective of this task during the quarter was to develop the basic statistical parameters needed to characterize the fracture system at Stripa. This has included calculating the true strikes and dips of the fractures from the relative orientations of fractures mapped in the drill core. Completion of this work has enabled comparison of the number and orientation of fracture sets or groupings defined by fractures intersecting the boreholes (Figure 1) with those defined by the orientations of the fracture traces mapped in the floor and walls of the experimental drift. There is close correlation between the number and orientation of fracture sets or groupings defined by the fracture data from the bottom of the three SBH boreholes and the data from the R and HG boreholes. Figure 2 is a contour plot of the poles to fracture planes for those fractures intersecting the R and HG boreholes and the fractures mapped in the walls and floor of the ventilation drift. A simple graphical technique has been used to define four major fracture sets on this contour diagram. Attempts to define the statistics of these sets or clusters using the computer code FRACTAN (Shanley and Mahtab, 1975) failed, because the criteria in the program for rejecting points on the periphery of a cluster are not sufficiently rigorous.

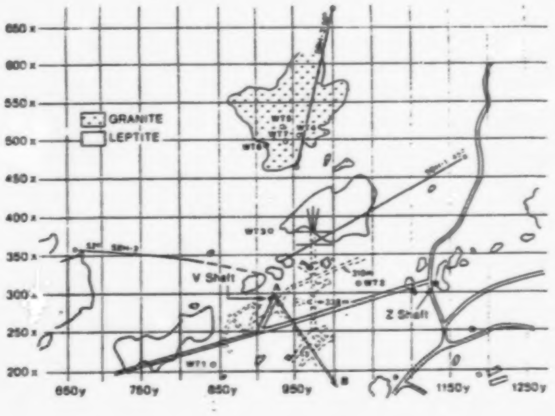

Figure 1. General Geology and Hydrology Borehole Locations. (Test excavations at the 338 m level are shown by the dashed line; squares are 50 meters on a side.)

The analyses of the fracture trace lengths show that the frequency-trace length data can be approximated by a log-normal distribution (Figure 3). Although the analysis is not yet complete, the fracture spacings also appear to follow a log-normal distribution. To complete the analysis of these data, an attempt will be made to modify the distributions so that they reflect the censoring imposed by the data collection process. Integration of the fracture statistics of orientation, lengths, and spacings will serve as a basis for attempting to define the degree of fracture interconnection within the rock mass surrounding the ventilation drift.

A topical report is being prepared that describes the fracture system at Stripa and the variation of basic fracture statistics throughout the test site. This report will also attempt to relate the basic fracture statistics to the standard rock mass engineering parameters, such as rock quality determinations (RQD).

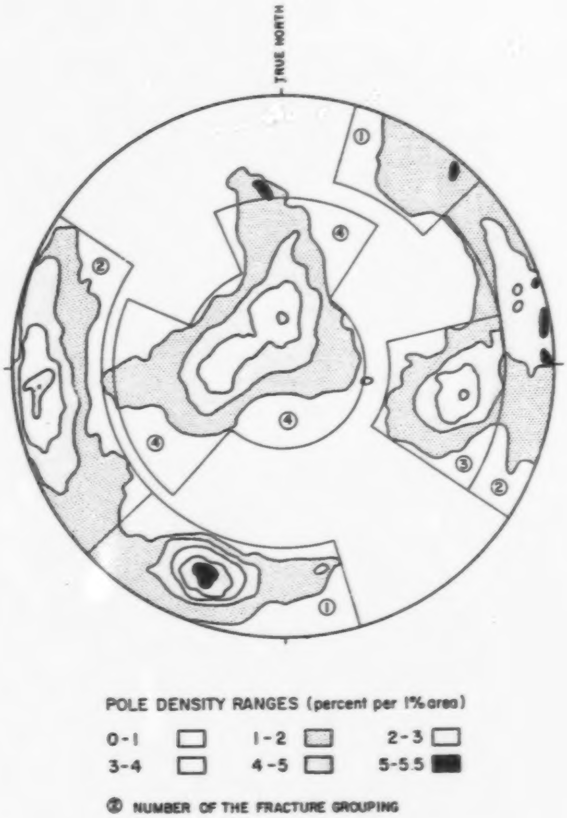

Figure 2. Contour Plot of Poles to the Fracture Planes Intersected by the R and HG Boreholes and the Fracture Planes Mapped in the Floors and Walls of the Ventilation Drift.

In parallel with the work on fracture characterization, characterization of the physical hydrogeology of the Stripa site has continued. In this quarter, a preliminary analysis has been made of the injection test data from the Stripa site using porous media and equivalent single-fracture concepts. The results of this analysis show that the calculated hydraulic conductivities range from 10^{-11} to 10^{-4} cm/s and that the corresponding equivalent single-fracture apertures rarely exceed 20 micrometers except for sections of HG-4 and HG-5, where the maximum calculated apertures are 25 and

35 micrometers, respectively, and the upper sections of the SBH boreholes, where values of 60 to 100 micrometers were calculated with one test interval giving a value of 180 micrometers. All of the injection test data will be analyzed, using basic fracture flow concepts so that the aperture distribution models necessary for integrating the hydrology and fracture data can be calculated.

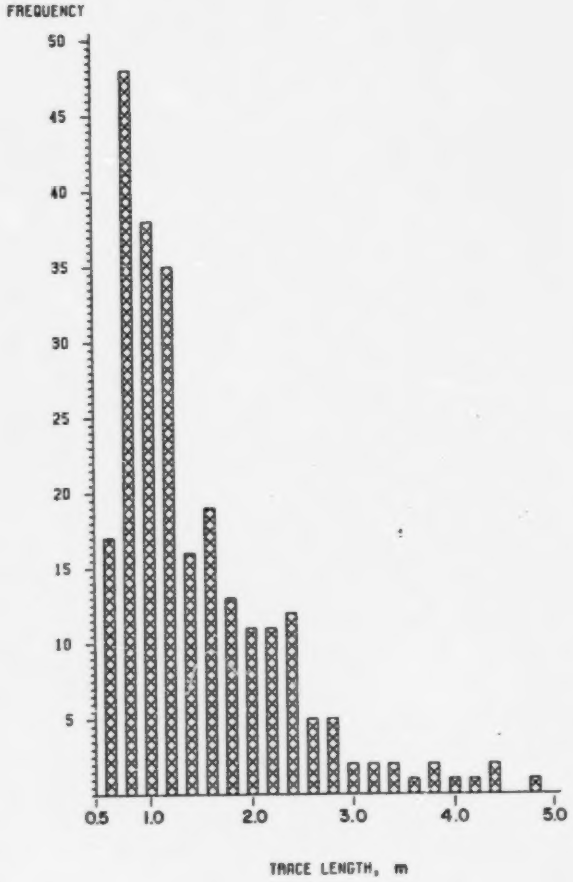

Figure 3. Distribution of Trace Lengths of Fractures From Set No. 1 Mapped in the Floor and Walls of the Ventilation Drift.

Work in this quarter on analyzing the laboratory and field pressure pulse tests has been limited mainly to an analysis of the basic equations used to analyze pressure test data. The analysis has shown the boundary conditions and subsequent solutions to be incompatible with the governing equation. Further analysis of the mathematics of the problem will be undertaken.

Permeability Size-Effect Study

In this quarter, four core samples containing natural fractures were prepared and instrumented. An initial attempt at creating an induced fracture, from a solid block of granite, that would be suitable for overcoring showed that the fracture plane formed by the wedge method produces a considerable amount of rock fragments and dust in the fracture plane. This problem and the best procedures for handling it will be discussed with other researchers before overcoring of the induced fractures is undertaken.

FUTURE ACTIVITIES

In the next quarter the statistical analysis of fracture spacings will be completed. The accuracy of the borehole TV-camera data will be assessed, and the usable data will be incorporated into the description of the fracture system. A report on the fracture system at Stripa will be prepared that will include both the fracture statistics and the rock mass engineering descriptions.

A detailed analysis of the injection test data, using basic fracture hydrology concepts, should be completed during the next quarter and should provide the fracture aperture data necessary to calculate directional permeabilities. The analysis of the basic mathematical procedures used to analyze pressure pulse tests will be completed, thus allowing the analysis of laboratory pressure pulse tests to be finished so that the field pressure pulse tests can begin.

Considerable progress should be made in the laboratory test of the different sized fractured rock cores. Testing of one of each of the different sized samples in the next quarter and recoring of the largest sample are scheduled to begin.

REFERENCE

Shanley, B. J., and M. A. Mahtab, 1975. FRACTAN: A Computer Code for Analysis of Clusters Defined on the Unit Hemisphere, U.S. Bureau of Mines, I.C. 8671, 49 pp.

SUMMARY

1.5 REGULATORY AND INSTITUTIONAL

Work conducted under this program element includes the development of licensing strategies, criteria, and guides necessary to identify the required information for, and the preparation of, licensing documents.

Work in the third quarter of FY 81 included review of draft regulations, attendance at NRC, Commissioner, and Advisory Committee on Reactor Safeguards (ACRS) meetings to discuss proposed regulations, and continued preparation of Licensing Topical Reports.

Review of the NRC status relative to publication of the draft 10 CFR 60 technical rule as a proposed rule continued. Licensing Program Office (LPO) staff attended several NRC and ACRS meetings during which the Commissioners and ACRS members were briefed by the NRC staff on the development of the rule. A draft letter setting forth concerns regarding the rule was provided to Headquarters (HQ) and, after revision, was forwarded to NRC. 10 CFR 60 was published in July as a Proposed Rule. Major efforts were also devoted to evaluating Draft 19 of the EPA rule (40 CFR 191) for disposal of high level wastes. Comments from within the NWTS program, coupled with technical supporting data from PNL, were consolidated and a preliminary copy forwarded to HQ during the last week in June. Final comments were provided to DOE in early July.

LPO representatives also participated in a NWTS meeting in Seattle on 2-4 June, 1981, to develop comments on the NRC's draft format and content guide for preparation of Site Characterization Reports (SCRs).

Development of a NEPA implementation strategy in conformance with the current NWTS program was intensified during the report period. Draft strategies were developed for consideration by NWTS, and a workshop was held in Germantown on 15-18 May to evaluate draft strategies and develop consensus on the most favorable approach. NEPA implementation input was provided at the SCR meeting noted above. Preparation of a draft Environmental Assessment to accompany the National Siting Plan was undertaken during the period.

Public information activities included the provision of drill site fact sheets at drill sites in Texas and Utah, news releases about Paradox and Permian Basin drilling, and preparation of a briefing package for the Basin and Range Province and Mississippi.

SUMMARY

1.6 TEST FACILITIES AND EXCAVATIONS

The scope of the test facilities and excavations task covers the acquisition, design, construction and development, and operation and maintenance of required field test facilities and excavations. The prime objective of this task is to provide the proper field testing facilities to support the field test activities of the nuclear waste isolation program.

In the alternative geology test facility mine screening project, computer programs for screening and ranking were completed. The MILS data base was adapted to the VAX system. A list of 66 mines meeting the general identification criteria was developed. The screened data base was supplemented by additional data from various sources.

WBS 1.6.1

PROJECT: Salt Test Facility Conceptual Design

PRINCIPAL INVESTIGATOR: Stearns-Roger Services Inc. (J. C. Mattern)

ONWI PROJECT MANAGER: T. M. Solack

OBJECTIVE

The objectives of this project are to:

- Develop a conceptual design for a salt test facility in a dome salt formation or a bedded salt formation
- Prepare cost estimates for the detailed engineering, construction, and decommissioning of the facility
- Prepare an environmental assessment for the facility
- Develop a Quality Assurance Plan for the Title I phase.

The specific location for the facility is not identified. Experimental test requirements will be defined by ONWI and the Westinghouse Advanced Energy Systems Division.

ACTIVITIES DURING THE REPORTING PERIOD

No progress report was submitted for the period.

WBS 1.6.2

PROJECT: Alternate Geology Test Facility--Mine Screen

PRINCIPAL INVESTIGATOR: Pincock, Allen & Holt, Inc. (J. R. Swaisgood)

ONWI PROJECT MANAGER: M. W. Anthony

OBJECTIVE

The principal purpose of this project is to identify suitable candidate sites for an Alternate Geology Test Facility (AGTF) in geologic media other than salt. Specific objectives include: (1) compiling a list or data bank of existing underground openings in suitable rock types which meet general identification criteria; and (2) developing a computer program to evaluate and compare candidate sites in granitic rocks using site-specific criteria to identify those sites with sufficient potential to warrant further investigation. The project will be performed using publicly available information only.

PROGRESS REPORTED PREVIOUSLY

The project was authorized on 12 November, 1980, with a contract date of 1 October, 1980. A detailed and comprehensive program plan was submitted. The computer data bases CRIB and MILS were reviewed, and arrangements were made to purchase the tapes. A thorough review of data made available was conducted.

After considerable review of the data files from CRIB and MAS, CRIB was found not to be as useful for this study as first thought, and efforts have been concentrated on working with MAS. The latest information and accessing programs for MAS have been obtained from the USBM. A draft of the general mine identification and site-specific criteria (Task 2) was submitted.

ACTIVITIES DURING THE REPORTING PERIOD

The computer programs for screening and ranking have been completed. The MILS data base was adapted to the VAX system. A list of 66 mines meeting the general identification criteria was developed. The screened data base was supplemented by hand-addition of data from various sources.

The final technical report is being drafted. All computer data base tapes and associated software will be submitted with the draft.

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ABBREVIATIONS

AEC	U. S. Atomic Energy Commission
AEGIS	Assessment of Effectiveness of Geologic Isolation Systems program (program replaces WISAP)
AESD	Advanced Energy Systems Division (Westinghouse)
AFR	away from reactor
ANL	Argonne National Laboratory
ANS	American Nuclear Society
ANSI	American National Standards Institute
ASTM	American Society for Testing Materials
BCD	Battelle Columbus Division
BCL	Battelle Columbus Laboratories
BEG	Bureau of Economic Geology (Texas)
BGI	Bechtel Group, Inc.
BLM	Bureau of Land Management, U.S. Department of the Interior
BNI	Bechtel National, Inc.
BNL	Brookhaven National Laboratory
BNW	Battelle-Northwest
BPMD	Battelle Project Management Division
BPNL	Battelle Pacific Northwest Laboratories
BWIP	Basalt Waste Isolation Project
BWR	boiling water reactor
CANDU	pressurized heavy water reactor (Canadian)
CFR	Code of Federal Regulations
CHLW	commercial high-level waste
Ci	curie
CRRD	Conceptual Reference Repository Description
CSM	Colorado School of Mines (Golden, CO)
D/D; D&D	decontamination and decommissioning
DOD	U.S. Department of Defense
DOE	U.S. Department of Energy
DOT	U.S. Department of Transportation
EIS	environmental impact statement
EMAD	Engine Maintenance, Assembly, and Disassembly Facility
EPA	U.S. Environmental Protection Agency
ERDA	U.S. Energy Research and Development Administration
FR	*Federal Register*
FRG	Federal Republic of Germany
FY (TD)	fiscal year (to date)
GIR	Gulf Interior Region
GJO	Grand Junction Office (Bendix Field Engineering Corporation)
GPM	Geologic Project Manager

HARC	Human Affairs Research Centers (Battelle-Seattle)
HEDL	Hanford Engineering Development Laboratory
HLW	high-level waste
HWR	heavy water reactor
IAEA	International Atomic Energy Agency
ILW	intermediate-level waste
IWG	Interface Working Group
KBS	Kärnbränslesäkerhet, Swedish Nuclear Fuel Supply Co., Safety Board Division
LANL	Los Alamos National Laboratory
LATA	Los Alamos Technical Associates, Inc.
LBL	Lawrence Berkeley Laboratory
LETCo	Law Engineering Testing Company
LLNL	Lawrence Livermore National Laboratory
LLW	low-level waste
LSU	Louisiana State University
LVDT	linear variable differential transformer; linear variable displacement transducer
LWR	light water reactor
MCC	Materials Characterization Center, Battelle, Richland
MIT	Massachusetts Institute of Technology
NASA	National Aeronautics and Space Administration
NBS	National Bureau of Standards
NEA	Nuclear Energy Agency; National Energy Act
NEPA	National Environmental Policy Act; National Environmental Protection Agency
NOAA	National Oceanographic and Atmospheric Administration
NPO	NWTS Program Office (formerly RL-C)
NRC	U.S. Nuclear Regulatory Commission
NTS	Nevada Test Site
NUS	NUS Corp. (Nuclear Utilities Services Corporation)
NWTS	National Waste Terminal Storage (program)
ONI	Office of NWTS Integration
ONWI	Office of Nuclear Waste Isolation
ORNL	Oak Ridge National Laboratory
OSHA	Occupational Safety and Health Administration
OWI	Office of Waste Isolation (predecessor of ONWI)
PNL	Pacific Northwast Laboratory (Battelle)
PSU	Pennsylvania State University
PWR	pressurized water reactor
QA	quality assurance

R&D	research and development
RHO	Rockwell Hanford Operations
RL-C	Richland Operations, Columbus Program Office, now NPO
SAC	Swedish-American Cooperative
SAI	Science Applications, Inc.
SCEPTER	Systematic Comprehensive Evaluation of Performance and Total Effectiveness of Repositories
SEM	scanning electron microscope
SF	spent fuel
SL	Sandia Laboratories
SRL	Savannah River Laboratory
SRP	Savannah River Plant
TBEG	Texas Bureau of Economic Geology
TRU	transuranic (contaminated) waste
USBM	U.S. Bureau of Mines
USGS	U.S. Geological Survey
WAES	WAESD, Westinghouse Advanced Energy Systems Division
WBS	Work Breakdown Structure
WES	Waterways Experiment Station, Corps of Engineers
WIPP	Waste Isolation Pilot Plant
WISAP	Waste Isolation Safety Assessment Program (replaced by AEGIS and WRIT)
WRIT	Waste-Rock Interactions Technology program (program replaces WISAP)

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